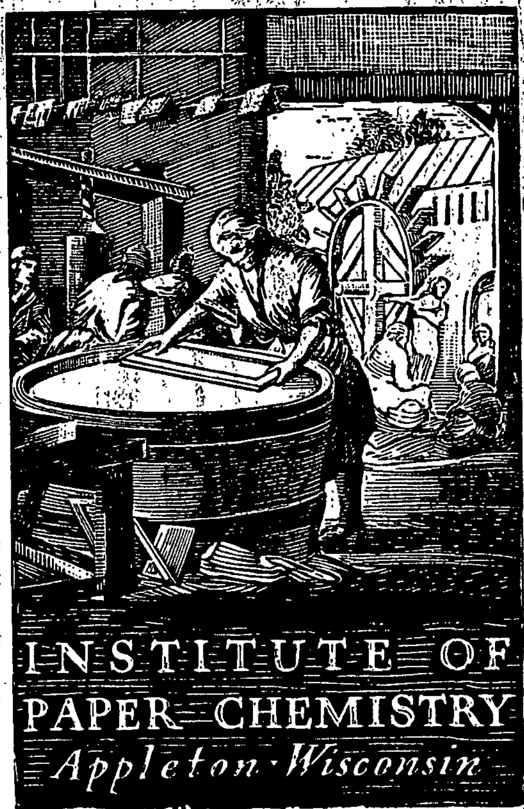

EXPERIMENTAL STUDIES OF SELECTED PHYSICAL PROPERTIES OF PAPER TISSUES IN RELATION TO THEIR SUBJECTIVE SOFTNESS

Project 2817

Report Three

A Progress Report

to

MEMBERS OF GROUP PROJECT 2817

January 22, 1971

THE INSTITUTE OF PAPER CHEMISTRY
Appleton, Wisconsin

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MEMBERS OF GROUP PROJECT 2817:

American Can Company

Cel-Fibe

Crown Zellerbach Corporation

Kimberly-Clark Corporation

Scott Paper Company

Westvaco Corporation

THE INSTITUTE OF PAPER CHEMISTRY
Appleton, Wisconsin

EXPERIMENTAL STUDIES OF SELECTED PHYSICAL PROPERTIES OF PAPER TISSUES IN RELATION TO THEIR SUBJECTIVE SOFTNESS

SUMMARY

The previous Project 2817 reports have dealt with the psychophysical aspects of tactile sensory response and a bibliography of the physical and subjective aspects of softness. This report attempts to relate particular physical properties of paper tissues to the subjective interpretation of their relative softness. Physical tests were conducted to evaluate surface properties and deformation properties of the samples. Surface properties consisted of differential densitometer profiles where surface irregularity was measured by the scatter (reflectance ratio) of an incident beam of light, low-pressure Chapman smoothness tests, and observations of the tissue surfaces by means of photographs made with grazing angle illumination. Tests of deformation properties comprised tensile modulus determinations, estimation of tensile modulus through sonic velocity measurements, and microcompaction measurements where the sheet indentation under a small-diameter probe was measured. The microcompaction measurements were used to calculate the apparent compressive moduli of the samples.

Two sets of paper tissue samples were tested, one a set of locally purchased toilet tissue samples and the other a set of tissue samples stored at the Institute for several years. These samples were mounted on paperboard cards and subjectively ranked unseen by a paired-comparison technique in which samples were presented to the subject in pairs in a random manner for his judgment as to the softer specimen.

The apparent compressive modulus appeared to have the best correlation with subjective softness (i.e., subjective ranking according to perceived softness).

The correlations for the two sample sets, however, were contradictory, the subjective softness increasing with the modulus values in one case and decreasing in the other. The magnitudes of the moduli for the two sample sets were quite different, leading to the conclusion that the correlative contradiction was due to differences in sensory emphasis in the process of subjective evaluation. The more deformable, lower modulus samples apparently were judged according to the distribution of irregularities while the less deformable samples apparently were judged according to deformability.

Nearly all of the samples possessed a degree of two-sidedness due to creping. A set of samples was evaluated with the creped side as a controlled variable. In every instance, the drum side (side of the tissue against the drier drum during the creping process) was judged softer than the felt side of a given sample. This was attributed to the more uniformly level surface created by the attachment of the tissue to the rigid, smooth drier drum during the creping process.

Analyses were run on the fiber furnishes of selected samples to determine whether gross differences in fiber furnish might be responsible for the differences in compressive modulus between the two sample sets. No gross differences were found and no explanation was apparent for the modulus differences other than the possibility that they could be the result of aging of the second sample set. In the samples containing groundwood, a decrease in softness rank with increasing groundwood content was observed.

The correlations between physical measurements and subjective softness developed in this work were very rough and inconsistent despite attempts to minimize the variables involved in the subjective evaluations. This points toward a conclusion that one's subjective response in comparatively evaluating tissue softness, even under well-controlled conditions, involves more than one perceptual dimension and is interpreted according to whichever stimuli provide the greatest perceptual difference.

INTRODUCTION

This is the third and final progress report issued for this project. The first report was a literature review of physiological and psychophysical aspects of tactile perception. The second report consisted of a bibliography of articles and papers pertinent to the perception and testing of the softness of paper products. This report is concerned with experimental attempts to develop physical correlates to the subjective perception of softness.

The individual's perception of softness involves the dynamic stimulation of tactile neurons to provide a pattern of signals that is sensed and interpreted in the brain. Physiological studies, described in Progress Report One, have indicated that the sensing neurons involved in tactile perception have varying degrees of sensitivity depending upon their type and body location. While these intraneural differences may provide a spectrum of sensory patterns, psychophysical studies, also described in Progress Report One have shown that regions of peak sensitivity exist along with threshold requirements necessary to be exceeded to elicit a sensor response. The threshold requirements appear to be in the form of minimum detectable pressure and movement. These requirements are interrelated so that an increase in the magnitude of one may decrease the threshold requirement of the other. Experiments with vibratory stimulation have shown that an individual's neural sensitivity is frequency dependent with a peak sensitivity (minimum threshold) in the region of 200 to 250 c.p.s.

It has been reasonably established that the process of tactile perception involves lateral motion between the innervated tissue (finger tip) and the perceived surface: This process is referred to as tactile scanning. Since the individual has very precise control over the pressure applied and the movement rate of his finger, it is anticipated that, for the reasons given in the preceding paragraph, this scanning process is self optimizing. That is, the individual tends to modify the applied pressure and scanning rate of the finger tip in such a manner as to obtain a maximum amount of information from the surface.

The purpose of this project has been to determine the feasibility of developing testable physical correlates to perceived softness in tissue products. Ideally, this would be accomplished through the development of a synthetic finger that could mechanically duplicate the scanning process. This would certainly require a good deal more knowledge of the physiology of the finger and the nervous system than is available. In lieu of such an approach, the best recourse is to determine experimentally those properties of a tissue that most influence one's perception of softness under specifically defined conditions.

EXPERIMENTAL APPROACH

The consensus of evidence from psychophysical studies is that tactual perception is a dynamic process. Relative motion is required to activate the neural senses. Nerve endings apparently respond to movement with varying degrees of sensitivity depending upon their size and their terminal configuration. The manner in which motion is transmitted to a particular nerve ending depends upon the body tissue in which it is imbedded. The manner in which the tissue transmits motion is dependent upon the interaction between the body tissue surface and the explored surface. Since all of the conditions are fixed excepting the coupling between the perceived and perceiving surfaces, it is the coupling interaction that is critical to our investigation.

For a given individual we may assume that the mechanical properties of his finger are constant; thus, presuming that he interprets the tactual information sensed by his finger in a systematic way, his interpretive response is predicated upon the geometric configuration and the mechanical response of the perceived surface (neglecting heat-transfer effects which would be very small in the case of an insulating material such as paper). Therefore, an individual's estimate of the relative softness of two paper tissue products should be predictable if certain properties of the tissues are known.

Inasmuch as the tactual process appears to be a dynamic process, it is the distributive nature of the paper tissue properties under dynamic conditions of pressure and shear imposed by the scanning finger that must be determined. It is not, however, a simple matter to define the mechanical actions imposed by a scanning finger due to the complex geometry of the interface and to the individual's modulation of the process to achieve optimum sensitivity. Instead of a comprehensive investigation directed toward the construction of a mechanical analog of an individual's finger, it may be possible to gain some clue to the physical correlates of perceived softness from the comparison of physical properties of paper tissues that may relate to distributive effects on the scanning finger.

A number of test measurements were considered and tried in the implementation of this approach. Most were directly related to the characterizations of the paper tissue surface or its z-direction compression properties under light loads. These tests will be described later in this section.

SELECTION OF SAMPLES

Twelve samples of toilet tissue were purchased locally. They consisted of six single-ply samples and six two-ply samples. All were in the form of rolls 11.4 cm. wide, serrated for tearing at intervals of 11.4 cm. Descriptions, identification, and general test properties are given in Table I.

Later, in the course of the work, when some experimental correlations had been indicated with the above samples, a second set of samples was introduced. These samples were samples of paper tissues on hand at the Institute. They were slab samples from 16 to 20-inch wide rolls and had been stored for approximately three years at 50% R.H., 72°F. Some general test data were available on these samples. Selected samples of this set were retested to determine the effects of storage. The samples are described in Table II.

SUBJECTIVE RANKING OF SAMPLES

The term "softness" as applied in this work pertains to a subjective response mediated by tactile and kinesthetic sensations. This is a generalized definition and, in terms of physical properties, it can encompass a number of dimensions. In judging softness, the method of the test largely influences the number of physical properties involved and the extent to which their involvement

TABLE I

GENERAL DESCRIPTION OF TOILET TISSUE SAMPLES

Code No.	Physical Appearance	Number of Plies	Basis Wt., $g./m.^2$	Basic Thickness, µm.	Tensile Breaking Load, g./cm.		Tensile Stretch, %		Tensile Modulus, $kg./cm.^2$	
					M.D.	C.D.	M.D.	C.D.	M.D.	C.D.
1-1	White, lightly embossed	1	17.8	88.4	110	43.1	13.9	4.2	68.6	192
1-2	White, lightly embossed	1	15.6	73.7	219	73.1	4.7	2.9	1770	618
1-3	White, embossed	1	19.9	78.0	130	34.3	11.3	6.2	198	128
1-4	White, creped	1	21.9	74.7	166	52.6	6.2	3.2	781	395
1-5	White, lightly embossed	1	20.8	75.2	93.3	37.8	16.5	4.3	86.3	163
1-6	White, embossed	1	18.7	68.6	129	23.7	5.0	5.5	46.3	101
1-7	White, creped, printed	2	16.5/16.4[a]	65.3/54.1[a]	94.4/133[a]	24.8/33.5[a]	11.2/15.9[a]	3.1/2.2[a]	189/124[a]	199/41.0[a]
1-8	White, creped	2	17.8/17.3[a]	73.4/82.3[a]	77.3/69.2[a]	16.6/17.2[a]	10.8/ 9.2[a]	3.1/3.8[a]	148/133[a]	122/94.0[a]
1-9	White, creped	2	20.9/21.1[a]	62.5/63.8[a]	51.3/58.2[a]	39.3/45.6[a]	16.4/15.8[a]	2.7/2.8[a]	97.4/111[a]	363/450[a]
1-10	White, creped	2	16.0/16.1[a]	72.9/72.6[a]	92.3/94.8[a]	20.4/24.4[a]	25.4/23.8[a]	13.4/11.8[a]	72.1/94.4[a]	49.1/72.7[a]
1-11	White, creped, printed	2	16.2/16.3[a]	77.2/80.5[a]	95.9/93.9[a]	20.9/21.1[a]	21.5/17.0[a]	13.6/12.5[a]	116/153[a]	48.6/45.8[a]
1-12	Blue-green/white, creped	2	16.6/16.6[a]	70.4/71.6[a]	81.5/82.1[a]	25.0/27.5[a]	16.8/16.5[a]	4.0/4.4[a]	131/131[a]	154/160[a]

[a] Top ply/bottom ply.

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TABLE II

GENERAL DESCRIPTION OF IPC PAPER TISSUE SAMPLES

(Retest data in parentheses, Samples C-1, D-1, E-1, H-1, K-1)

Code No.	Physical Appearance	Number of Plies	Basis Weight, g./m.^{2}	Basic Thickness, µm.	Tensile Breaking Load, g./cm. M.D.	Tensile Breaking Load, g./cm. C.D.	Tensile Stretch, % M.D.	Tensile Stretch, % C.D.	Tensile Modulus, kg./cm.^{2} M.D.	Tensile Modulus, kg./cm.^{2} C.D.
A-1	White, creped	2	17.1	102	56	17	15.9	12.6	93.1	87.3
A-4	White, creped	1	22.0	84	109	27	6.1	2.9	311	290
B-1	White, creped	2	17.5	114	127	17	20.6	3.1	84.2	114
C-1	White, creped	1	17.8	69(58)	94(140)	50(72)	6.0(5.5)	2.9(2.8)	1020 (1150)	774(923)
C-2	Blue, creped	2	18.0	91	70	41	9.7	2.0	216	464
D-1	White, creped	1	23.2	101(83)	62(100)	22(34)	9.8(10.2)	2.8(3.2)	147 (173)	183(201)
D-2	Pink, creped	2	15.9	112	56	14	20.2	11.6	60.7	51.8
E-1	White, creped	2	16.2	79(64)	69(104)	17(24)	10.8(10.1)	3.3(4.0)	81.1(245)	179(181)
E-4	White, embossed	1	21.4	89	62	15	4.6	4.5	316	103
F-2	White, creped (very fine)	1	16.6	74	184	38	1.7	1.3	4960	1243
G-1	Pink, creped	1	21.5	119	93	34	9.9	4.5	374	227
H-1	Pink, creped	1	21.4	109(83)	51(80)	22(34)	23.2(23.3)	3.3(3.5)	68.8(88)	152(205)
H-3	White, creped	2	18.0	99	65	23	18.7	3.2	94.0	193
I-2	White, creped	2	15.4	84	40	13	14.9	2.7	81.0	133
J-1	White, creped	2	15.9	94	72	17	8.9	3.4	267	132
J-4	White, creped	1	22.9	104	66	23	9.9	3.1	147	180
K-1	Pink creped	2	16.8	99(66)	84(145)	12(20)	14.3(16.0)	3.2(3.4)	121(162)	87.9(128)
K-4	White, lightly embossed	1	22.4	130	49	12	11.5	6.2	67.7	30.8
L-1	Pale yellow, creped	1	18.3	89	86	27	6.6	2.0	410	339
L-2	White, creped	2	16.8	99	49	20	8.9	2.9	142	198

is emphasized. For example, a softness judgment determined by bending or crumpling a specimen could depend upon a number of physical factors, with particular emphasis on flexural properties; such a judgment might be quite different than a judgment based upon perpendicular closure of the finger to the sheet surface.

The softness judgments discussed here are relative judgments, not absolute judgments. As pointed out earlier (Progress Report One) man's ability to make absolute judgments is very much limited and is extended only by the number of physical dimensions involved. The ability to make relative judgments, however, is very precise – small differences can be sensed and judgments can be made based upon the individual's weighted response. Under conditions evoking responses to a number of physical variables, points of emphasis may shift from dimension to dimension as the individual seeks differences or difference patterns that he considers significant. This seeking process can in turn produce an enhanced sensitivity to certain variables, much as one's ability to interpret visual patterns by focusing upon particular elements.

Simplification through the restriction of the number of variables in an experiment is usually the most desirable approach for the determination of correlations. In this case, the number of variables, since they are unknown, is best reduced by simplification of the softness judgment procedures to involve a minimum of sensory manipulations. Psychophysical studies [Stevens and Harris (1) and Ekman, et al. (2)] have shown, for example, that under certain conditions correlations can be developed between the subjective estimation of roughness and the physical variables of grit size and coefficient of friction for emery cloth and sandpaper samples. The surfaces in these cases possess a fair degree of geometric order in contrast to paper surfaces. These samples were evaluated by stroking with the fingertips under conditions such that the fingertips were the only means of sensory communication with the specimens. If they exist, simple correlations can be developed providing the number of physical variables involved is sufficiently reduced.

In order to restrict the judgment of softness to its simplest physical basis without resorting to elaborate mechanisms for control of the closure of the finger to the tissue surface, the specimens were taped to 4 x 5-inch pieces of paperboard in such a manner that the specimen edges could not be felt. Four-ply thicknesses (4 single-ply sheets; 2 double-ply sheets) were used in each instance.

Judgment evaluations were made by a subject seated at a table in front of a screen. A slot between the screen and the table top allowed the subject to handle specimens presented on the other side of the screen without observing them. Several methods of specimen presentation and evaluation were employed in the initial experimentation. These methods included ranking of a set of specimens presented at once to the subject, magnitude estimation where arbitrary number values were assigned to the specimens by the subject according to their apparent softness, and the method of "paired comparisons." Three male subjects participated in the tests and were identified by their initials: H. C., J. T., and L. L.

The paired comparison method of evaluation was found to give the best reproducibility and agreement between subjects. By this method, rankings were obtained from the subject's evaluation of pairs of specimens. A pair of specimens was presented and the subject was asked to judge which was the softer. Specimen pairs drawn from a set of samples were presented in a random fashion until each sample had been compared to every other sample. Results of the comparisons were recorded by the experimenter on a prepared form and the final ranking of the samples was determined from the number of times each sample specimen had been judged softer.

Results of the paired-comparison tests for both sample sets are listed in Table
A copy of the form used in recording the test data is included in Appendix I.

PHYSICAL TESTING

Physical tests were directed toward the characterization of the surfac geometry of a paper tissue sample under no load or very light loads and the stud the response of the sample to very light loads applied over small areas perpendi to the plane of the sheet (z-direction). In addition to tests having second-or relationships to these surface and z-directional properties (i.e., basis weight, thickness, tensile strength, and tensile modulus), the following tests were made

- Differential densitometer profiles
- Grazing angle photographs
- Low-pressure Chapman smoothness
- Sonic modulus
- Microcompaction
- Compressive modulus.

All testing was carried out on specimens conditioned to 50% R.H., 72°F.

Differential Densitometer Profiles

The differential densitometer was devised at the Institute. It is designed to measure variations in the optical properties over small distances al the surface of a sheet of paper. The instrument measures the ratio of the verti cally reflected light from a high-angle (in the case of the work discussed here) incident beam for a very small area (0.84-mm. diameter) and a larger surrounding area (12.70-mm. diameter). It will be described in a future publication and wa the subject of a paper presented by Dr. R. M. Leekley at the 1969 TAPPI Graphic
Conference.

TABLE III

SOFTNESS RANKING OF TISSUE SAMPLES
BY PAIRED-COMPARISON METHOD

Sample, 2782-	Number of Times Ranked Softer[a] H. C.	J. T.	L. L.	Av. Ranking
	Sample Set I (Toilet Tissues)			
1-1	19	11	18	8.00
1-2	10	14	12	5.83
1-3	1	0	1	0.33
1-4	9	13	9	5.17
1-5	3	5	7	2.50
1-6	0	0	0	0.00
1-7	9	10	8	4.50
1-8	7	9	8	4.00
1-9	16	21	22	9.83
1-10	16	13	15	7.33
1-11	5	4	4	2.17
1-12	16	18	20	9.00
	Sample Set II (IPC)			
A-1	10[b]	18	22	10.00
A-4	9	15	17	8.20
B-1	6	13	13	6.40
C-1	9	5	6	4.00
C-2	7	19	8	6.80
D-1	6	19	18	8.60
D-2	13	15	26	10.80
E-1	16	23	32	14.20
E-4	7	2	8	3.40
F-2	7	14	6	5.40
G-1	1	0	1	0.40
H-1	5	11	8	4.80
H-3	10	31	31	14.40
I-2	16	32	36	16.80
J-1	16	21	24	12.20
J-4	9	13	13	7.00
K-1	15	20	20	11.00
K-4	12	24	30	13.20
L-1	10	17	27	10.80
L-2	6	10	8	4.80

[a] Total, each set ranked twice.

[b] H. C. ranked Set II one time only.

In the performance of a test, a mounted specimen is scanned over an interval of 3 inches at a rate of 0.06 in./min., and the ratio, R_s/R_l (reflectan of the small area ÷ reflectance of the large area), is recorded on a recording potentiometer. Specimens of the toilet tissue samples were tested using a white light beam at an incident angle of 85° to emphasize surface roughness effects. direction of the scan was made in the cross-machine direction so that the incide light would be directed in the machine direction. Some of the embossed specime were scanned in the machine direction to enhance the effects of embossing. Portions of the resulting graphs for each of the specimens are shown in Fig. 1, 2, 3, the ordinate representing the reflectance ratio and the abscissa the distance along the specimen.

The purpose of the test, as applied to this study, was to determine the surface variations in terms of variations in reflectance ratio. In order to red the variation profiles to single numbers, the reflectance ratios were read at qua inch intervals along the charts, and from these sets of values, mean values, sta deviations, and coefficients of variation were computed. These are listed in t order of average subjective softness ranking of the samples in Table IV.

Grazing Angle Photographs

Photographs at 20X magnification were made of selected regions of the densitometer specimens using 85° incident illumination in the same direction as densitometer illumination. Visual comparison of the photographs gave no indicat of their relative softness rankings. The photographs do, however, document the regions scanned in the densitometer. These photographs are included in Appendi of this report.

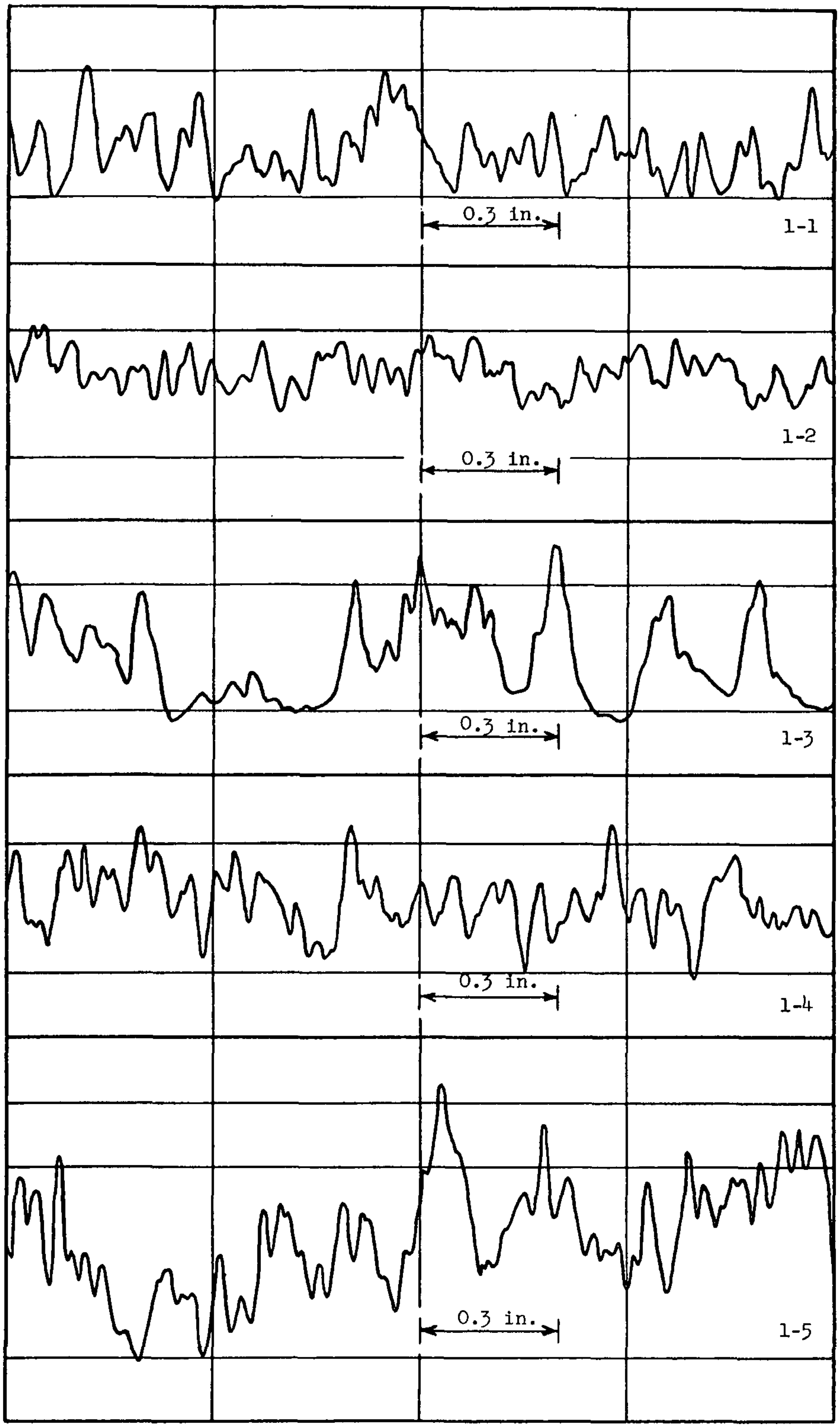

Figure 1. Reflectance Ratios over a 1.8-inch Span
in the Cross-Machine Direction

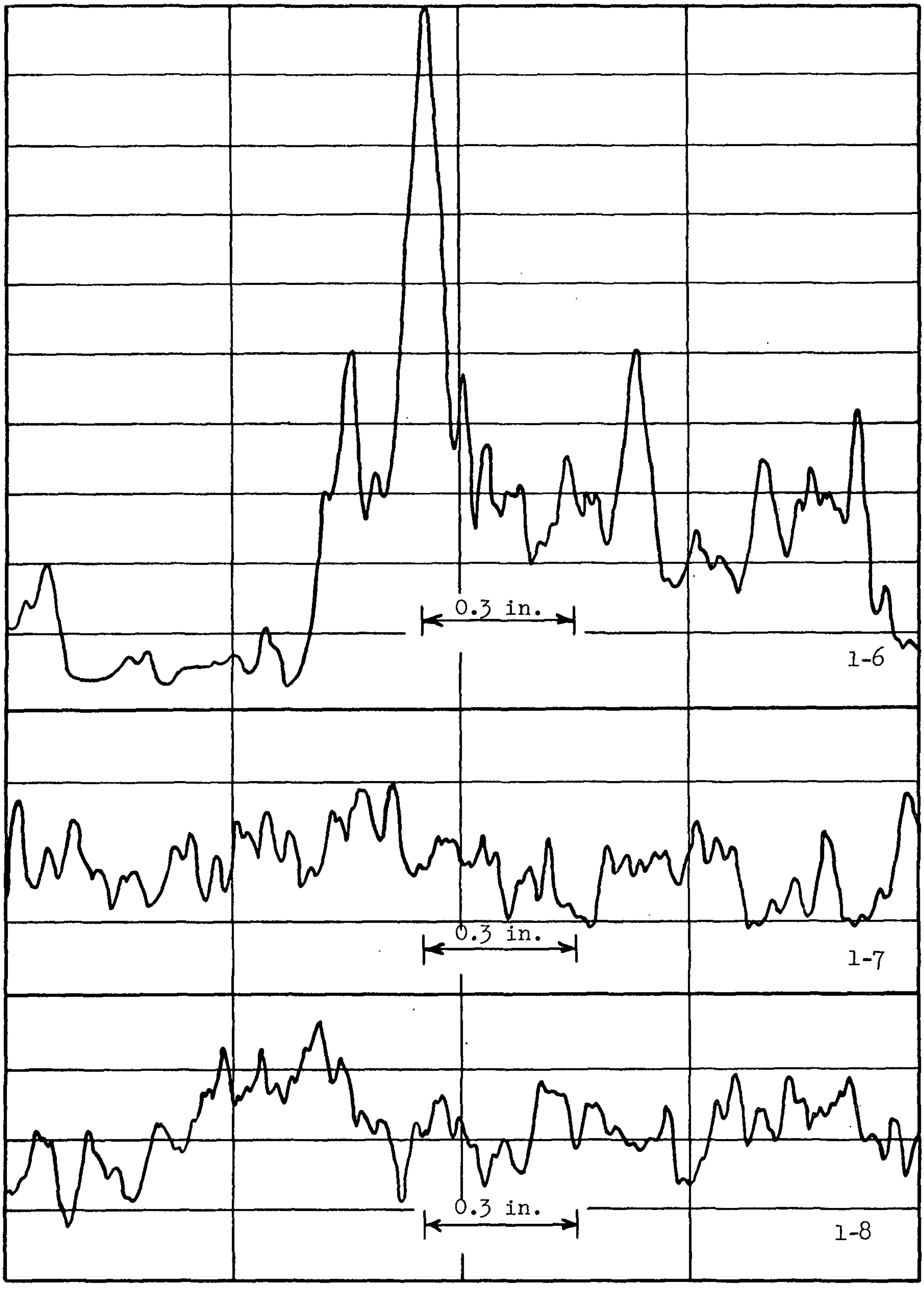

Figure 2. Reflectance Ratios over a 1.8-inch Span
in the Cross-Machine Direction

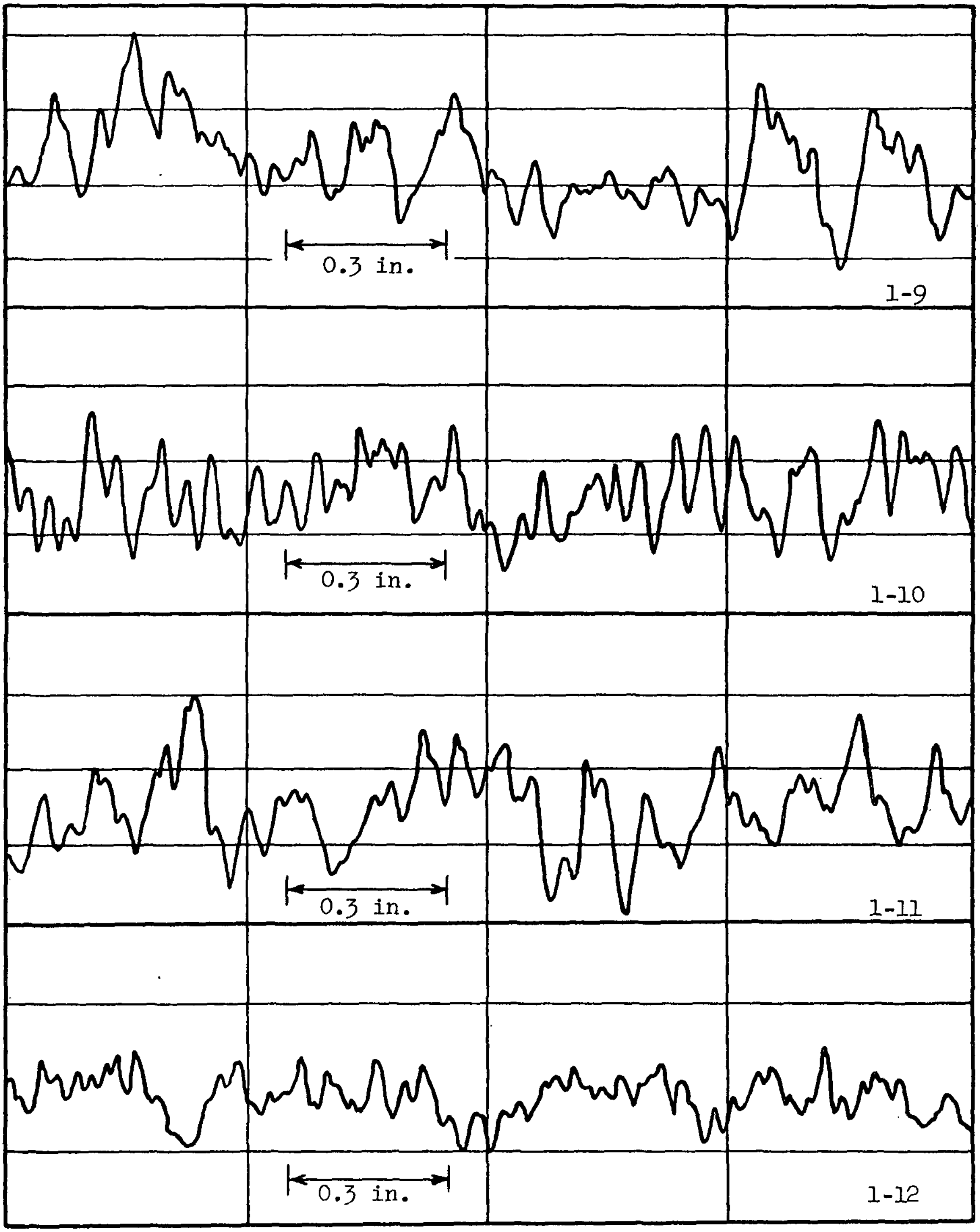

Figure 3. Reflectance Ratios over a 1.8-inch Span
in the Cross-Machine Direction

TABLE IV

MEANS AND VARIATIONS OF REFLECTANCE RATIO DATA

Sample, 2782-	Reflectance Ratio Mean	Std. Deviation	Coefficient of Variation, %
1-9	51.9	5.01	9.65
1-12	47.1	3.06	6.49
1-1	48.0	4.00	8.33
1-10	45.5	4.35	9.56
1-2	54.2	3.08	5.68
1-4	60.7	4.46	7.34
1-7	48.0	3.92	8.16
1-8	51.3	5.76	11.22
1-5	56.1	8.01	14.27
1-11	45.4	4.58	10.08
1-3	49.7	7.26	14.60
1-6	19.1	17.72	92.77

Low-Pressure Chapman Smoothness Tests

The Chapman smoothness test is normally run at pressures ranging from 177 to 708 p.s.i. (124 to 498 g./mm.^{2}). These pressures are significantly higher than the pressures applied during tactile scanning, the latter being of the order of a few g./mm.^{2} It was not anticipated that the Chapman smoothness values obtained under the standard test conditions would have any correlation to subjective softness. Consequently, the Chapman tester was modified by removing the hydraulic load cylinder and inverting the unit so that specimens could be loaded against the contact prism with weights.

Photographs were made at 3x magnification of the 41° scattered light from a 90° incident flashbulb source. A number of trials were made at increasing pressures from 0.033 g./mm.^{2} until sufficient contact area was achieved with the softest (subjective) specimen to obtain a photograph. The minimum pressure producing sufficient contact was 5.04 g./mm.^{2} The remainder of the specimen set which consisted in total of six of the toilet tissue samples was tested at this pressure. The reflectance values ranged from 5 to 7% and were not consistent with the softness rank.

The photographs (see Appendix II) indicated very little contact area, and when ranked visually according to apparent contact area, did not fall especially into the order of their subjective softness ranking. While contact pressures equivalent to tactual pressures could be attained in this test, the test condition is one of a rough deformable surface in contact with a smooth, rigid surface producing local pressures at actual points of contact somewhat higher than the apparent pressure. This condition does not simulate the case of tactile scanning where both surfaces are deformable and local contact pressures are more nearly equal to the apparent pressure. Higher specimen contact pressures would increase the contact area, yielding more readable photographs; however, the condition would become further removed from the tactual situation. For this reason, this approach was pursued no further.

Sonic Modulus

Sonic modulus tests were run on the toilet tissue samples prior to the Instron tensile tests as a rapid means of estimating their Young's moduli. Later tests were run on the second set of tissue samples to obtain a comparison of the sonic and tensile moduli.

Tests were run on a Morgan Dynamic Modulus Tester, Model PPM-5 (H. M. Mor Co., Inc., Cambridge, Mass.). This device measures the time of travel of a 5000-H wave between a sending and a receiving probe. By varying the distance between the probes, a series of readings can be taken that when plotted describe a straight lin with a slope equal to the sonic velocity of the 5000-Hz wave in the sheet. The sonic modulus can then be determined from the equation:

$$\tilde{E} = \rho c^2$$

where:

c = sonic velocity, cm./sec., and

ρ = mass density, g.-sec.^{2}/cm.^{4}, (density in g./cm.^{2} divided by the gravitational constant, g = 981 cm./sec.^{2}).

Tests were run on 1-in. wide specimens in the machine direction at probe separation ranging from 2 to 10 cm. The calculated sonic moduli are presented in Table V, along with the tensile moduli. The two moduli appear to be in rough agreement; however, neither demonstrates any sort of first-order agreement with softness ranking. Had the softness been evaluated in another manner where stiffness would be an important factor, some correlation with modulus might have been expected.

TABLE V

SONIC AND TENSILE MODULUS DATA

Sample, 2782-	Sonic Modulus, kg./cm.^{2}	Tensile Modulus, kg./cm.^{2}
Sample Set I (Toilet Tissues)		
1-9	174	97
1-12	145	131
1-1	97	69
1-10	97	77
1-2	1051	1770
1-4	1525	781
1-7	194	189
1-8	126	148
1-5	179	86
1-11	156	116
1-3	273	198
1-6	583	46
Sample Set II (IPC)		
I-2	121	81
H-3	374	94
E-1	373	81
K-4	95	68
J-1	282	267
K-1	141	121
D-2	65	61
L-1	648	410
A-1	117	93
D-1	395	147
A-4	961	311
J-4	202	147
C-2	323	216
B-1	95	84
F-2	6370	4960
H-1	97	69
L-2	313	142
C-1	1224	1020
E-4	449	316
G-1	388	374

Microcompaction

As discussed earlier, precise mechanical duplication of the tactile scanning process would be very difficult. A more expedient approach would be to characterize the point-to-point variations in surface properties of the tissue products, presuming that it is the distribution of variations to which one's tactile sensors respond. This distribution could be determined by a series of static tests.

It was proposed at the first Project 2817 group meeting (March 12, 1970) that a study of the mechanical response of various tissue products to compression applied through small probes would be made. The IPC Fiber-Load-Elongation-Record (FLER) was adapted for this purpose by fitting the load arm with a small-diameter probe and the addition of a movable stage.

Load was applied to the probe through the load arm by means of a chain. The load was varied by raising and lowering the chain with a drum winch directly connected to a recording chart. With the lightest chain on hand, a load of 1.60 per cm. of chart along the y-axis could be applied. Probe movement was measured by means of a linear variable differential transformer in units of 11.085 µm./cm. of chart along the x-axis.

Initial trials with a 0.004-inch diameter probe were not successful because of the high unit pressures applied (197.5 g./mm.^{2} per cm. of chart).

From a series of measurements of fingerprints taken from the subjects performing the softness evaluations, it was determined that the average width of a dermal ridge was 0.025 to 0.030 inch. A 0.031-inch diameter probe was selecte for the remainder of the work; this diameter corresponded to the width of a derma ridge and provided a unit pressure of 3.29 g./mm.^{2} per centimeter of chart.

Load-deformation curves were determined for the toilet tissue samples using one- or two-ply specimens, depending upon the number of plies in the product. Replicate tests yielded wide variations in curves for a given sample with no specific correlation to subjective softness rank.

Tests were subsequently run in which the probe was first applied to the specimen with a 3.2-g. load (6.60 g./mm.^{2}) followed by a load increase to 9.6 g. (19.80 g./mm.^{2}). This loading was repeated at twelve intervals, unequally spaced, over a 24-mm. span in the machine direction of the specimen. The results were analyzed statistically to obtain a measure of their distribution and variation as summarized in Table VI.

At this point, it was felt that a more representative measure of the sample compressibility might be obtained by testing a thicker pad of sample. The tests were then repeated using 4-ply specimens in all cases. The variations in response to a load increase from 6.60 g./mm.^{2} to 19.80 g./mm.^{2} are given in Table VII.

Attempts to obtain a correlation of the distribution of responses to loading were fruitful only to the extent that a general discrimination could be made between the softest and harshest specimens. Corrections for basis weight and caliper differences did not improve the correlation.

Compressive Modulus

Load-compaction curves were determined for the 4-ply specimens over a load range of zero to 27.0 g./mm.^{2} Three tests were run on each specimen at 5-mm. intervals along the machine direction. As was the case in all of the preceding tests, the side of the sample tested was the same side as was touched in the subjective tests. Compaction values were taken from the curves at load intervals of

TABLE VI

VARIATIONS IN RESPONSE TO A LOAD CHANGE FROM 3.2 TO 9.6 g.[a]
(ONE- AND TWO-PLY SPECIMENS)

Sample, 2782-	Compaction[b] from 6.60 to 19.80 g./mm.^{2} Average, µm.	Std. Deviation, µm.	Coefficient of Variation, %
		Single Ply	
1-1	5.8	2.0	74.4
1-2	4.4	0.8	18.6
1-3	5.6	2.2	38.6
1-4	4.6	2.0	43.5
1-5	5.2	1.2	23.2
1-6	4.8	1.3	27.1
		Two Ply	
1-7	13.6	5.4	39.8
1-8	14.8	4.2	28.4
1-9	19.0	1.15	12.8
1-10	9.0	1.85	20.7
1-11	11.8	3.4	29.1
1-12	8.8	1.0	11.5

[a] Probe 31-mil diameter.

[b] Twelve separate measurements.

TABLE VII

VARIATIONS IN RESPONSE TO A LOAD CHANGE FROM 3.2 TO 9.6 g.[a]
(FOUR-PLY SPECIMENS)

Sample, 2782-	Compaction[b] from 6.60 to 19.80 g./mm.^{2} Average, µm.	Std. Deviation, µm.	Coefficient of Variation, %
	Single Ply		
1-1	102.0	23.0	22.6
1-2	28.2	6.3	22.5
1-3	80.0	12.9	16.1
1-4	26.6	2.5	9.6
1-5	49.5	13.2	26.6
1-6	49.6	23.2	46.9
	Two Ply		
1-7	37.8	6.9	18.3
1-8	41.2	5.7	13.9
1-9	28.2	5.0	17.7
1-10	30.7	4.2	13.6
1-11	31.6	4.9	15.5
1-12	31.6	4.3	13.5

[a] Probe 31-mil diameter.

[b] Twelve separate measurements.

3.29 g./mm.^{2} (1 cm. of chart). The values were averaged for the three curves to obtain an average response curve. These average values were converted to relative deformations by dividing by the 4-ply caliper. A series of values was obtained fo each sample that when plotted against load produced a curve that was nearly linear to a load of approximately 13 g./mm.^{2} The use of the standard caliper is not appropriate to the rigorous measurement of deformation since it is determined under a load of 6.32 g./mm.^{2}; it is also known that the 4-ply caliper of a sheet seldom is equal to 4 times its single-ply caliper due to the nesting of the plies. For these reasons, the calculated deformation is referred to as the "apparent compression." The resulting curves are shown in Fig. 4-7, for both sets of samples.

An apparent compressive modulus was determined from the initial slope of each curve. These moduli are listed in Table VIII. Two separate trends can be seen in the relationship between softness rank and compressive modulus. The modulus appears to increase with the softness ranking of the toilet tissue samples, while the modulus of the second set of samples appears to decrease with increasing softness rank. Seemingly, this is a contradiction; however, it will be shown later in the discussion of the experimental results that a plausible explanation can be made for this inversion.

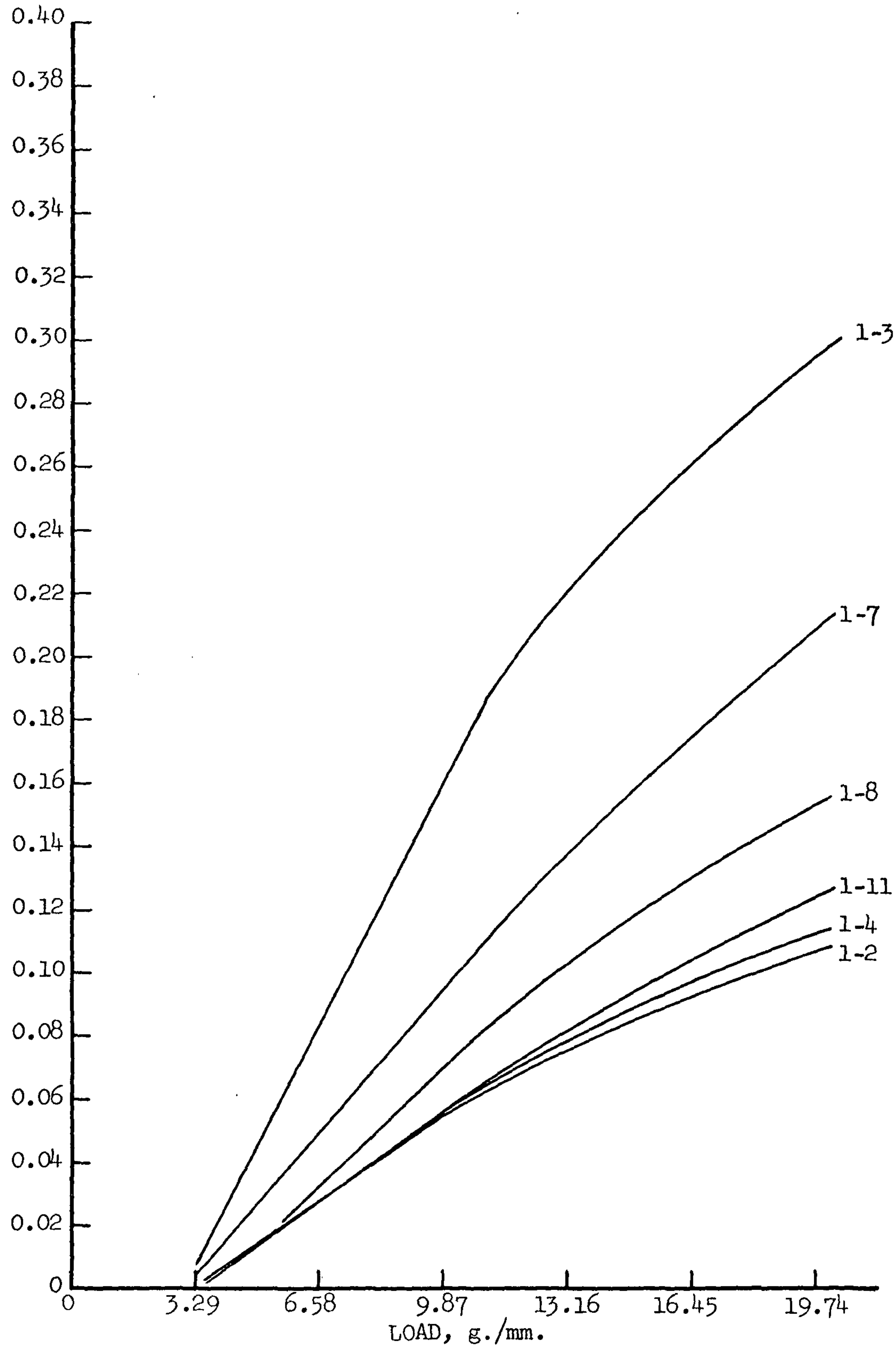

Figure 4. Apparent Compression Versus z-Direction Load —
Sample Set I (Toilet Tissues)

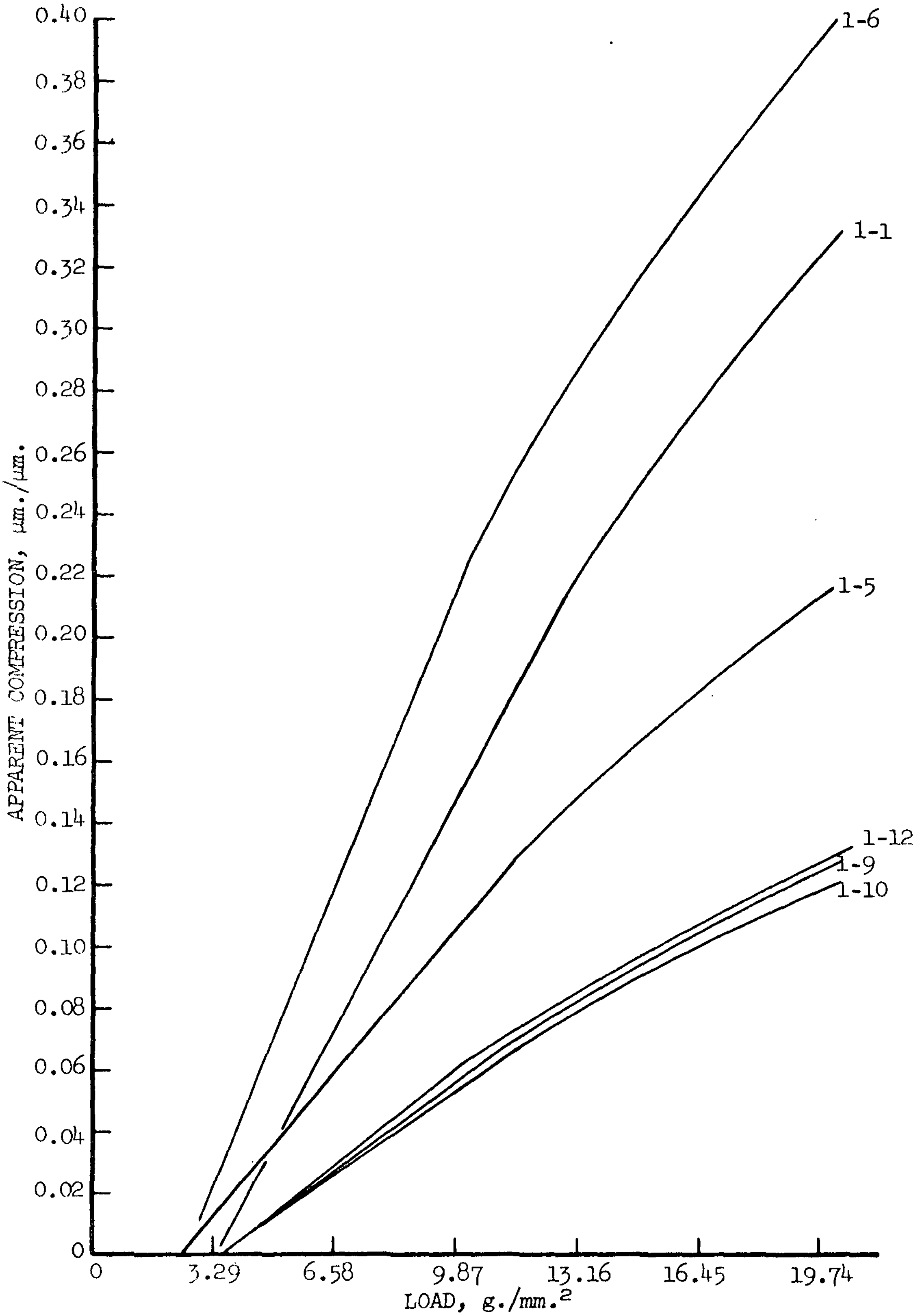

Figure 5. Apparent Compression *vs.* z-Direction Load – Sample Set I (Toilet Tissues

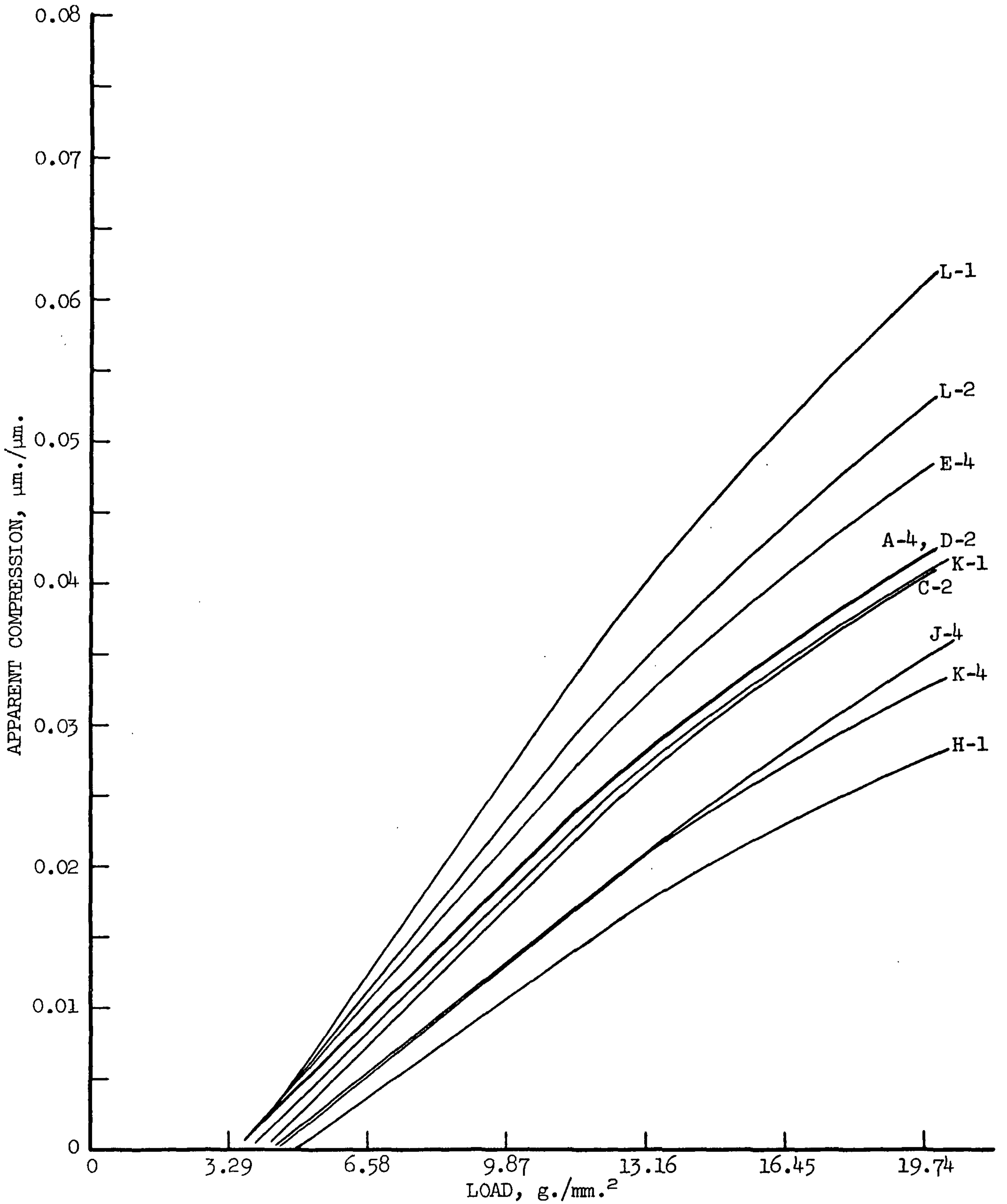

Figure 6. Apparent Compression vs. z-Direction Load – Sample Set II (IPC)

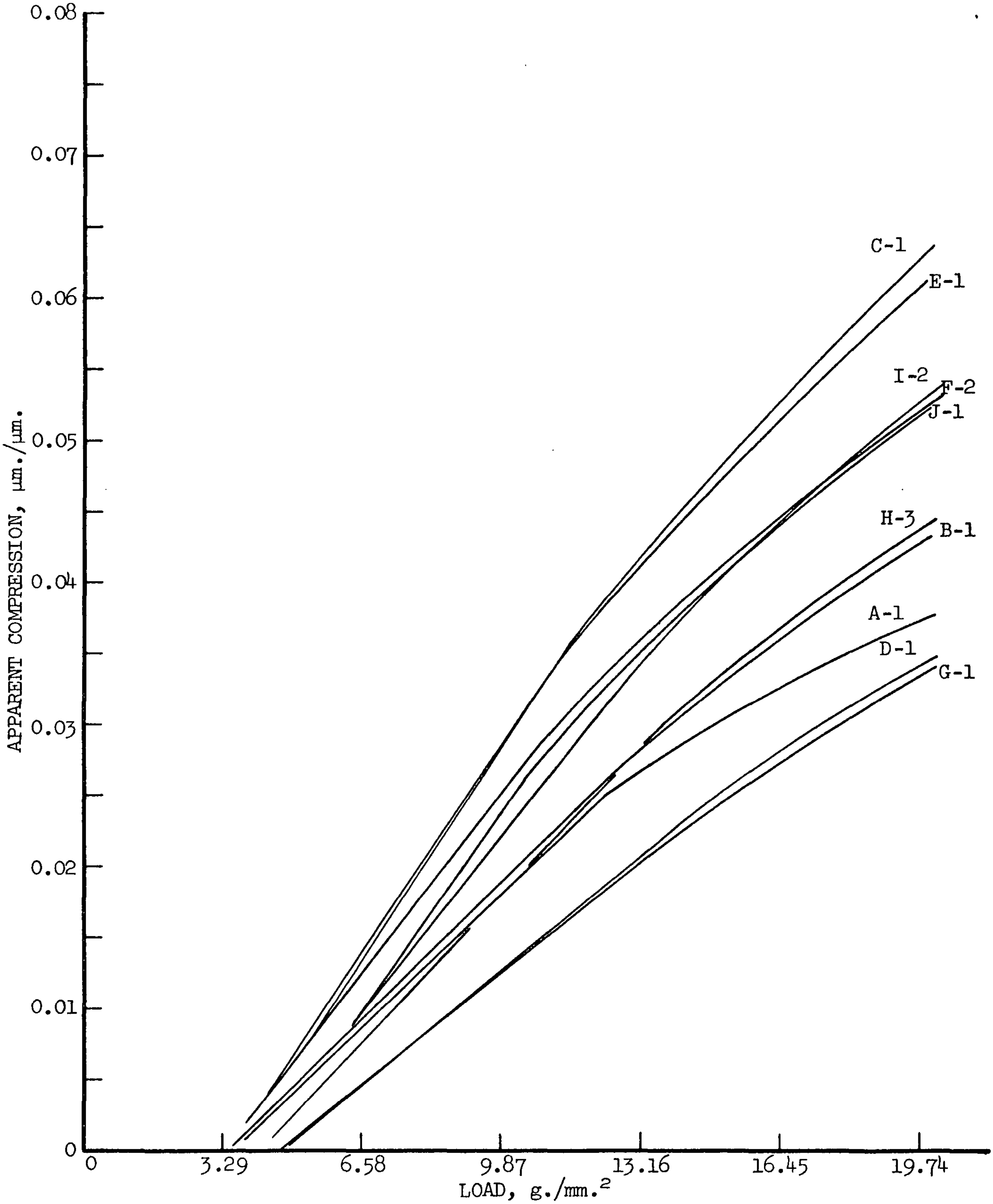

Figure 7. Apparent Compression vs. z-Direction Load - Sample Set II (IPC)

TABLE VIII

COMPRESSIVE MODULUS – 4-PLY, 31-MIL DIAMETER PROBE

Sample, 2782-	Av. No. Times Ranked Softer	Compressive Modulus, 4-Ply, g./mm.^{2}
	Sample Set I (Toilet Tissues)	
1-9	9.83	113
1-12	9.00	106
1-1	8.00	44
1-10	7.33	122
1-2	5.83	122
1-4	5.17	113
1-7	4.50	94
1-8	4.00	87
1-5	2.50	70
1-11	2.17	113
1-3	0.33	43
1-6	0.00	34
	Sample Set II (IPC)	
I-2	16.80	268
H-3	14.40	308
E-1	14.20	226
K-4	13.20	416
J-1	12.20	237
K-1	11.00	339
D-2	10.80	336
L-1	10.80	251
A-1	10.00	370
D-1	8.60	406
A-4	8.20	336
J-4	7.00	416
C-2	6.80	339
B-1	6.40	339
F-2	5.40	259
H-1	4.80	476
L-2	4.80	272
C-1	4.00	219
E-4	3.40	294
G-1	0.40	416

EXPERIMENTAL RESULTS

SUBJECTIVE RANKING

"The actual perception of any individual are few and not exactly repeated: those he can remember are even fewer, and most confused and distorted." – George Santayana.

The subjective ranking of the samples is the critical criterion for the evaluation of the physical tests performed in this project. The extent to which subjective judgments can be reproduced determines the maximum empirical correlation obtainable. An inability to reproduce a ranking order under identical physical conditions is indicative of either low organoleptic sensitivity or inconsistencies due to shifting sensory emphasis. The former condition is related to just-noticeable difference thresholds and should result in relatively small shifts in the rank of a given specimen – the greater the number of positions spanned, the greater the magnitude of the physical dimension sensed. The second condition could produce larger shifts in position since it does not follow that the magnitude of response elicited by one physical dimension necessarily predicates the magnitude produced in another dimension (e.g., the surface roughness and compressibility are not necessarily related; the ranking order of several materials compared on the basis of roughness need not be the same ranking order obtained when they are ranked according to compressibility). Unfortunately, both conditions appear likely to have occurred in the paired-comparison evaluations. For this reason it was necessary to determine the degree to which ranking discriminations could be made confidently.

Average rankings and standard deviations were computed for duplicate evaluations (one exception) by three subjects, thereby comprising five sets of data in one case (the IPC samples) and six sets in the other. The results are shown graphically in Fig. 8 and 9. It is apparent that the range of values for a given sample overlap those of adjacent samples.

The statistical "t" test was applied to determine the existence of real differences in the mean values of neighboring samples having nearly equal standard deviations. These determinations were made at a 90% confidence level. Proceeding from the lowest ranked specimens, groupings were determined that exhibited no real differences in mean rankings. These groupings are bracketed in Fig. 8 and 9.

Six groups were found for both sample sets. It is interesting to note that the six categories of response correspond to an information transmission of 2.59 bits. The channel capacities for the perceptual continua of frequency-modulated cutaneous vibration and duration of stimulation are 2.8 and 2.3, respectively (see Report One, p. 45). Were the similarities in transmitted information not fortuitous, the implications would be that the ranking process involves absolute discrimination (see Report One, p. 39-45) and the testing technique has restricted the number of sensory dimensions involved to one or two.

CORRELATION OF COMPRESSIVE MODULUS AND SUBJECTIVE SOFTNESS

The response of a specimen to compressive loading was found to fluctuate from area to area under the compressing probe, resulting in a range of moduli which were averaged when the deformation under increments of load were averaged. This variation limits the degree of differentiation between samples and makes groupings of the sample data an expedient approach to obtaining relevant correlations.

In attempting to correlate compressive modulus and subjective softness, the data can be grouped in either of two manners. Groupings can be based on increments of subjective softness or on increments of compressive modulus.

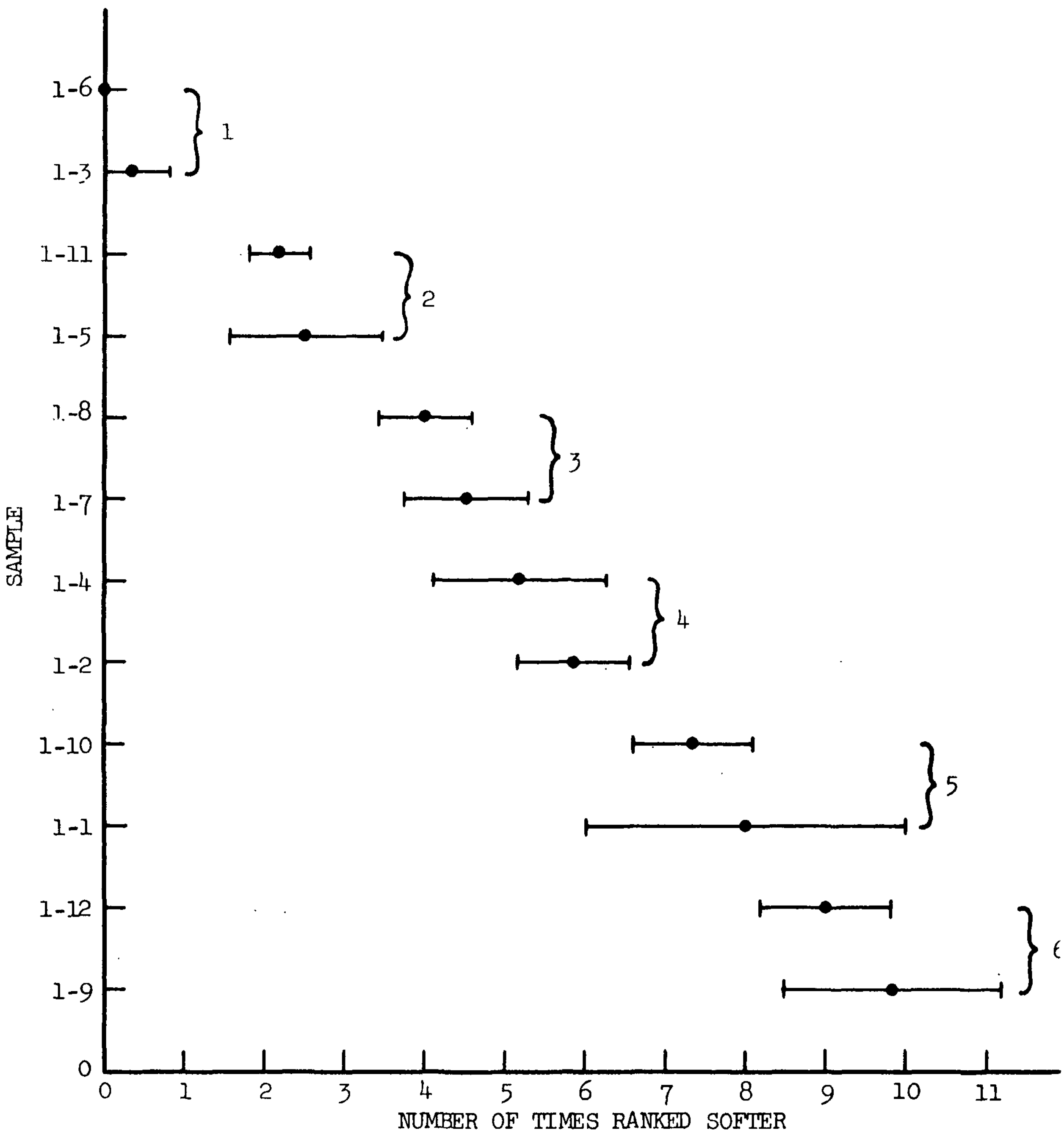

Figure 8. Softness Ranking of Sample Set I

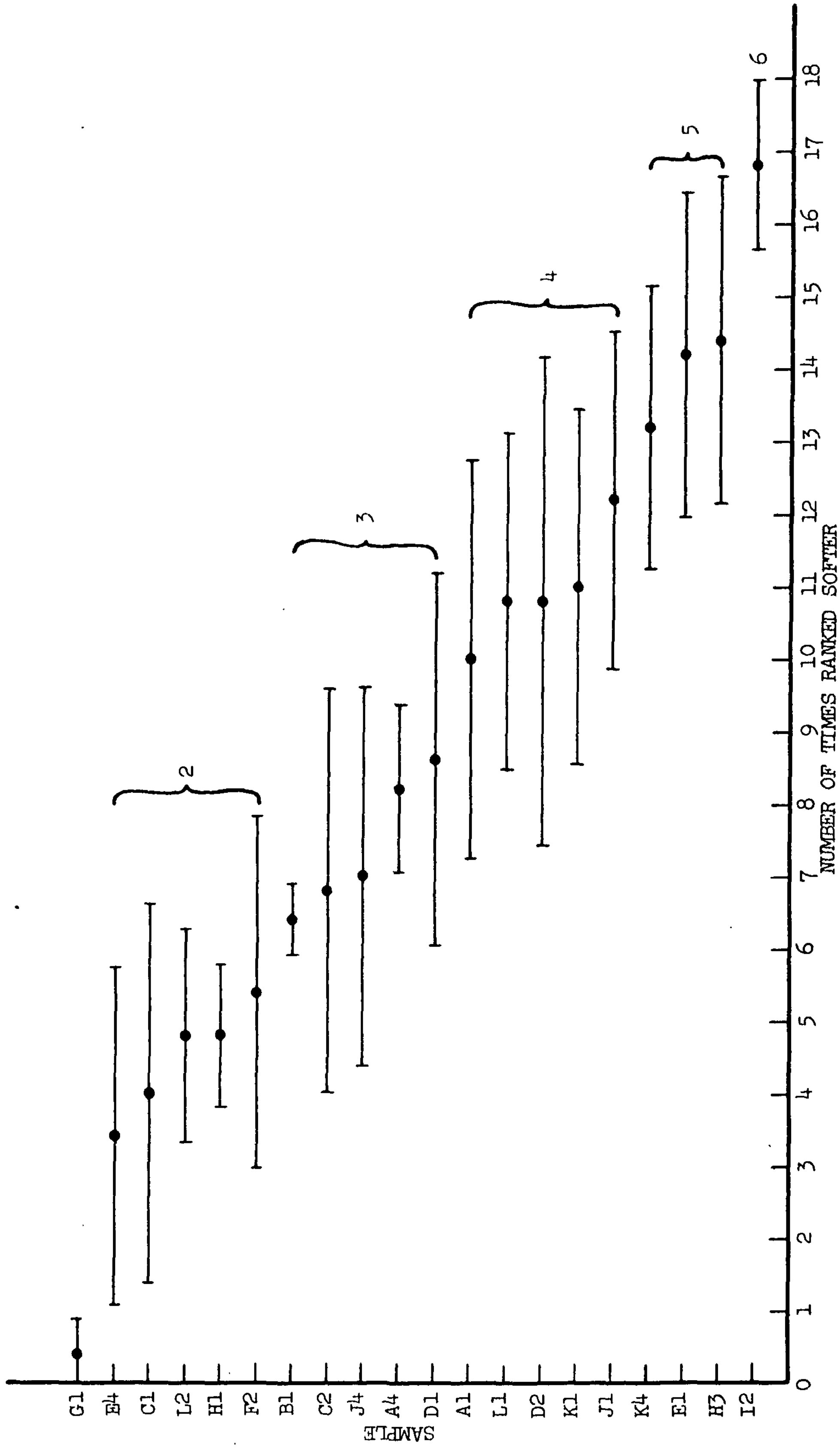

Figure 9. Softness Ranking of Sample Set II

Inasmuch as the softness ranking data were best interpreted according to statistica groupings, the average moduli were viewed according to these groupings.

A second variable that appears to enter into the judgment of the data is sample thickness. The sample thickness does not appear to vary systematically wit the compressive modulus and it is fairly uniform as a group-averaged value, as show in Table IX. Although these data are not readily reduced to provide a defined correlation between thickness and subjective softness, it is apparent for observations of thickness and softness rank over narrow ranges of compressive modulus that sample thickness does influence the judgment of softness. The average top-ply thickness of Sample Set I, the toilet tissues, was 73.2 μm. with a standard deviati of ± 6.4 μm. The average thickness of Sample Set II, the IPC samples, was 97.0 μm with a standard deviation of ± 15.0 μm. It was found that by not including data for samples having thickness outside the 2-σ limits of the set (one sample in each set) an improvement was effected in the correlation of the compressive modulus and subjective softness.

Average subjective softness rank is plotted as a function of the 4-ply compressive modulus, excluding the two data points described above, in Fig. 10. While the correlations are not good, the contradiction in the response of the two sample sets is apparent — softness rank increases with the modulus in the case of the toilet tissue samples and decreases with the modulus of the IPC samples. It i also observed that the respective moduli of the sample sets differ roughly by a factor of four. Apparently, the two cases represent a difference in the dimensio perceived in forming a subjective judgment of softness.

If it is presumed that, in the process of forming a judgment of softness under the conditions defined in this work, one is sensitive to the magnitude of vertical compression over a limited range beyond which he responds to local variat

TABLE IX

THICKNESS AND COMPRESSIVE MODULUS OF SAMPLES
GROUPED ACCORDING TO SUBJECTIVE SOFTNESS

Group		Sample, 2782-	Av. No. Times Ranked Softer	Compressive Modulus, 4-Ply, g./mm.^{2}	Av. Thickness, Top Ply, µm.
			Sample Set I (Toilet Tissues)		
I		1-6	0.0	34	69
		1-3	0.33	43	78
	Av.		0.16	38	74
II		1-11	2.17	113	77
		1-5	2.50	70	75
	Av.		2.34	92	76
III		1-8	4.00	87	73
		1-7	4.50	94	65
	Av.		4.25	90	69
IV		1-4	5.17	113	75
		1-2	5.83	122	74
	Av.		5.50	118	74
V		1-10	7.33	122	73
		1-1	7.80	44	88[a]
	Av.		7.66	83	80
VI		1-12	9.00	106	70
		1-9	9.83	113	62
	Av.		9.42	110	66
			Sample Set II (IPC)		
I		G-1	0.40	416	119
II		E-4	3.40	294	89
		C-1	4.00	219	69
		L-2	4.80	272	99
		H-1	4.80	476	109
		F-2	5.40	259	74
	Av.		4.48	304	90

[a] Value greater than 2-σ limits.

TABLE IX (CONTD.)

THICKNESS AND COMPRESSIVE MODULUS OF SAMPLES
GROUPED ACCORDING TO SUBJECTIVE SOFTNESS

Group	Sample, 2782-	Av. No. Times Ranked Softer	Compressive Modulus, 4-Ply, g./mm.^{2}	Av. Thickness, Top Ply, µm.
		Sample Set II (IPC)		
III	B-1	6.40	339	114
	C-2	6.80	339	91
	J-4	7.00	416	104
	A-4	8.20	336	84
	D-1	8.60	406	101
Av.		7.40	367	99
IV	A-1	10.00	370	102
	L-1	10.80	251	89
	D-2	10.80	336	112
	K-1	11.00	339	99
	J-1	12.20	237	94
Av.		10.96	307	99
V	K-4	13.20	416	130[a]
	E-1	14.20	226	79
	H-3	14.40	308	99
Av.		13.93	317	103
VI	I-2	16.80	268	84

[a] Value greater than 2-σ limits.

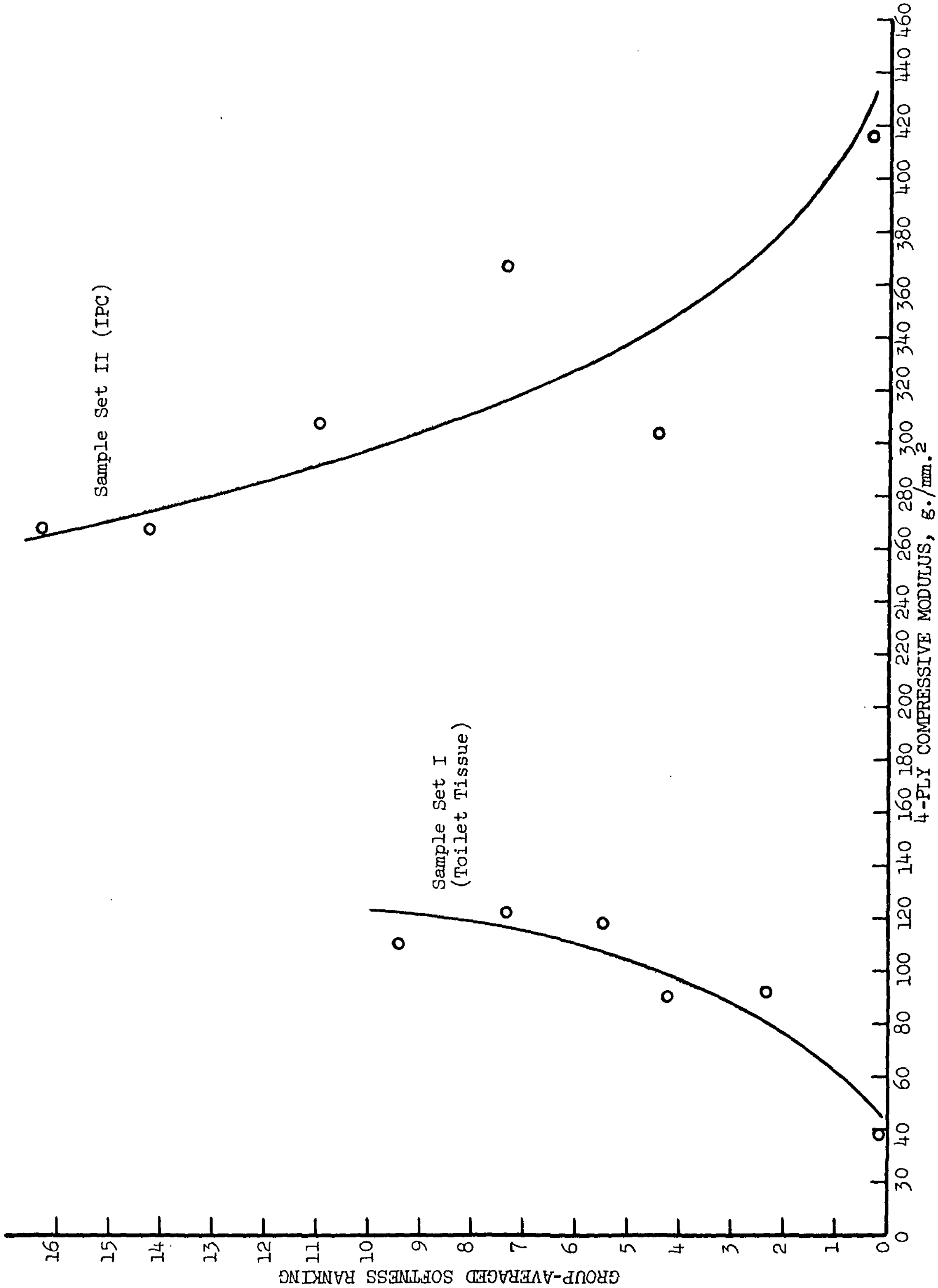

Figure 10. Average Softness Ranking Versus 4-Ply Compressive Modulus

in vertical compression, a reasonable explanation can be constructed to explain the contradictory behavior of the two sample sets: In the evaluation of Sample Set II, one responds primarily to the magnitude of vertical compression, whereas the moduli of Sample Set I are sufficiently low that one cannot perceive differences between samples and consequently judges according to localized variations sensed by tactile scanning. In this latter case, one would expect greater local variations in the more readily deformable material (lower modulus) resulting in a comparative judgment of inferior softness. Thus a set of samples having very low compressive moduli could be ranked with increasing softness as the modulus increases, as shown by the trend of the data for Sample Set I.

CREPING - TWO-SIDEDNESS EFFECTS

Creping is commonly used to improve the softness of tissues. This is illustrated by the fact that nearly all of the tissue specimens employed in this work were creped. Creping performs two functions: It reduces the bonding, giving the sheet more of a nap, and it increases the bulk of the sheet thereby increasing its compressibility. Embossing is similarly employed for these purposes.

The creping process involves the interactions of adhesion to the drier drum and sheet and fiber properties and doctor configuration. The balance of the properties determines whether creping can occur and the frequency of the crepe and its uniformity.

The cross section of a creped sheet has the configuration of a series of cursive "m's" with legs directed toward the drier and the broad loops on the drier felt side. This gives the sheet a definite two-sided appearance and the sides can be distinguished visually. The manner in which one responds to the different side of a tissue sheet and the microcompressibility properties of the two sides could give further clues to the sensory processes of softness judgment.

Five samples were selected from both sample sets for microcompaction tests and softness ranking. Four-ply test specimens were prepared with the drum sides of each ply facing the same direction. A suffix "D" was added to the identification of specimens prepared with the drier drum side as the tested or sensed surface, and the suffix "F" was used to denote the use of the felt side as the tested or sensed surface. Apparent compression data are plotted in Fig. 11 and softness ranking results and calculated compressive moduli are presented in Table X.

In every case, the drum side of a given sample was judged softer than the felt side. The drum and felt specimens of Samples H-1 and C-1 from Sample Set II were separated in ranking, while the drum and felt specimens of each sample from Set I had adjacent rankings. This ranking is contrary to what one might expect since it would seem that the broad loops on the felt side would provide a smoother, less discontinuous surface. However, when one considers that the drum side is formed against a rigid surface, it is evident that surface irregularities resulting from fluctuations in the creping process will be expressed on the felt side causing it to become the coarser surface.

The compressive modulus data appeared to have little bearing on the softness ranking of these samples. Surface texture apparently played a more pronounced role, but evidently on the level of fiber furnish since the ranking tended to transcend the well-defined two-sidedness resulting from the crepe. None of the tests thus far have provided a satisfactory characterization of surface texture. Possibly, a comparison of fiber furnishes would indicate how the fibers themselves influence surface texture and also indicate a basis for the large difference between the compressive moduli of the two sample sets.

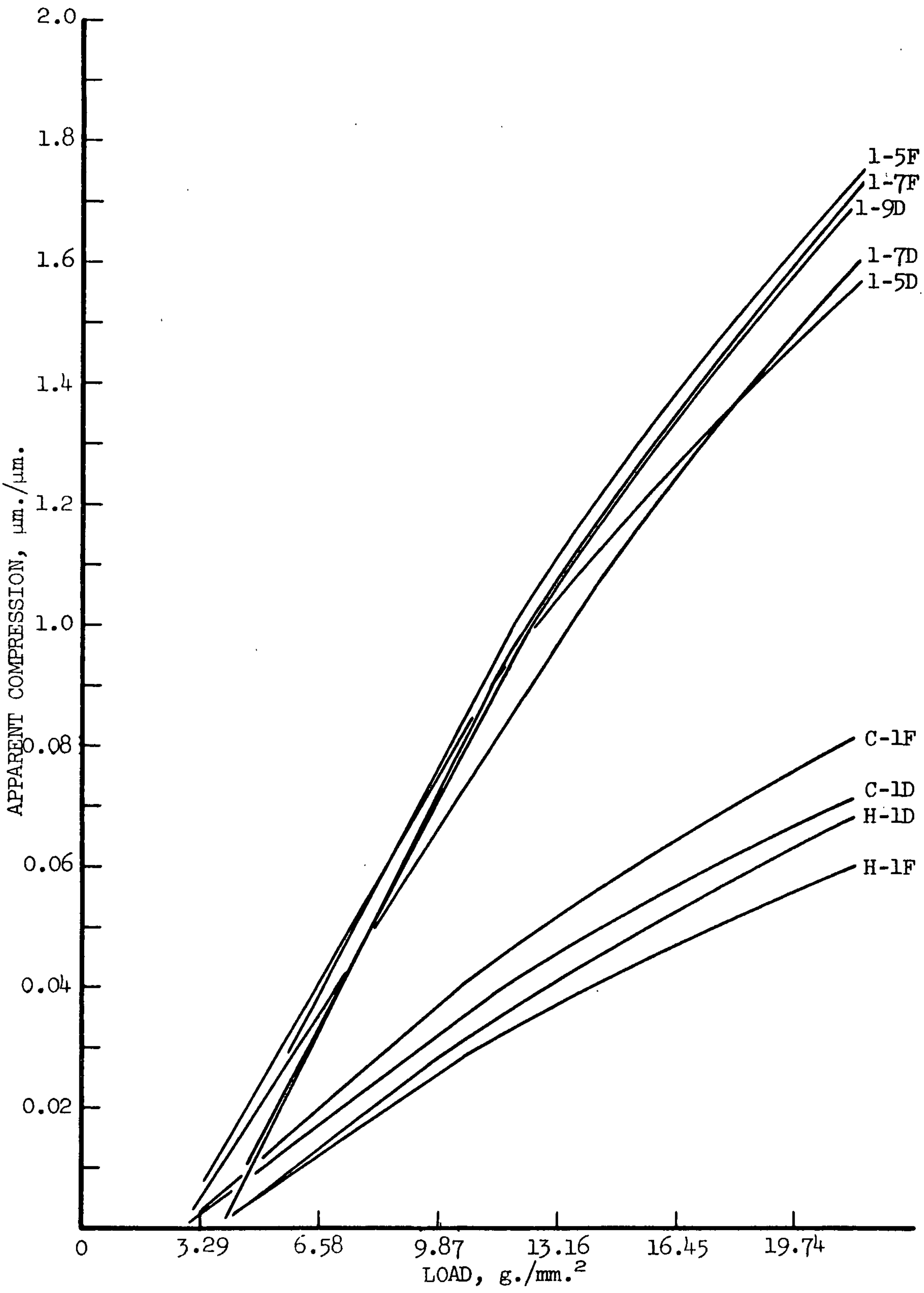

Figure 11. Apparent Compression vs. z-Direction Load – Samples Tested According to Creped Side

TABLE X

SOFTNESS RANKING AND COMPRESSIVE MODULI OF TISSUE SAMPLES
TESTED ACCORDING TO CREPED SIDE

(F = felt side; D = drier drum side)

Sample, 2782-	No. Times Ranked Softer (Two Trials) L. L.	J. T.	Av. Ranking	Thickness, μm.	Compressive Modulus, 4-Ply, g./mm.^{2}
1-9D	18	14	8.00	62	82
1-9F	15	11	6.50	62	82
H-1D	13	10	5.75	83	212
C-1D	10	10	5.00	58	219
1-7D	7	10	4.25	65	108
1-7F	7	7	3.50	65	88
C-1F	2	8	2.50	58	194
H-1F	4	4	2.00	83	244
1-5D	4	2	1.50	75	94
1-5F	0	0	0.00	75	88

FIBER ANALYSIS

Selected samples were analyzed for fiber content with the results shown in Table XI. The samples were further analyzed for species, fiber cutting, fibrillation, and fiber morphology; these results are given in Appendix II.

The samples of each set in Table XI are listed in descending order of softness ranking. The samples containing groundwood show a decrease in softness rank with increasing groundwood content. The remaining constituents indicate no obvious trends.

The second reason for this analysis was to determine whether some gross differences in furnish might be responsible for the more than 4-fold difference in the compressive moduli of the two sample sets. There were no stark differences in the fiber furnishes and the reason for the modulus difference was not explained. One possibility is that the differences could represent a result of aging effects on Sample Set II.

While some predictions can be made regarding the softness of a sheet on the basis of its furnish, sheets can be made from the same furnish that will be judged quite different in softness. The relationship between fiber furnish and sheet structure is a cause-and-effect relationship and one cannot be divorced from the other. Elements of sheet structure that are important to the perception of softness but are not defined in structural terms (nap, for instance) may be described indirectly by characterization of the fiber furnish. An intensive study of furnishes, however, would have extended beyond the scope of this project.

TABLE XI

FIBER ANALYSIS OF TISSUE SAMPLES

(Fiber content, % – to nearest 5%)

Sample, 2782-	Softwood Bleached Kraft	Softwood Unbleached Sulfite	Softwood Bleached Sulfite	Softwood Bleached Sulfite, Alpha Grade	Hardwood Bleached Kraft	Hardwood Bleached Sulfite	Groundwood
Sample Set I (Toilet Tissues)							
1-9	35					60	5-
1-10	60-		25		15+		
1-7	35+		10+			35	15+
1-5	20					50-	30+
1-6	55		5+		40-		
Sample Set II (IPC)							
E-1	5+		45		45-		5
K-1	75		trace+			10+	10
D-1	20-	trace	30		40-		15-
H-1	35-				65+		
C-1	50			45-	10-		

CONCLUSIONS

The experimental phase of this project was directed toward the problem of developing quantitative physical expressions of the character and mechanical respons of a paper tissue surface that would relate to the subjective sensations of softness If the sensory process were straightforward, that is, if one's judgment of softness depended solely upon perceived intensities along one or two physical dimensions, a straightforward solution to this problem would exist. At present however, all that is known about the sensory process in regard to the perception of intensity is that it is not straightforward. According to Stevens (3), "The mediation of sensory intensity must count itself among the major puzzles of neurology."

The experimental work has shown that, while we can distinguish by physical tests between the softest and harshest samples of a sample set, we cannot describe a psychophysical relationship in the interval between these extremes. Apparently, no uniform relationship exists; thus, in comparing two samples, our tactile senses seek differences without obligation to dimensional consistency. A judgment may be based upon ease of deformation in one instance and surface roughness in another, depending on which dimension presents the greater difference. We appear to be dealing with more than one perceptual dimension and one's subjective response may be the result of an interpretation within the brain rather than a simple perception of intensity.

Halldane (4) in a discussion of psychophysical problems related to materials has stated: "The principal input from environmental stimuli for the covert behavioral responses of perception and cognition comes through the visual, auditory, skin, proprioceptive, olfactory, gustatory, and organic sensory channels. Now we cannot say that a person has so many photons of vision, a neural discharge rate of perception, or a chemical concentration of memory because a covert (hidden) response is not an easily identifiable physical parameter nor is it even guaranteed to occur. All we can say is that under favorable conditions, that [sic] there could be a correlation between an arrangement of physical parameters which is the stimulus, and a consistent indication or acknowledgment by an observer which is assumed to be the covert response."

Some success has been achieved in the correlation of the intensity of certain physical parameters with subjective magnitude where the physical stimuli and the subjective interpretation are simple and well defined [e.g., loudness, temperature, vibration - see Stevens (3)]. Of the correlations that have been developed, tactual roughness and tactual hardness come the closest to having the physical correlates most nearly tantamount to the physical processes involved in the perception of softness.

Softness is defined in mechanical systems as a relative measure of ease of deformation or lack of mechanical resistance. Attempts to correlate these physical properties with the subjective interpretation of softness have not been successful, yet we know from the mechanical actions involved that these properties are involved in the sensing process. It appears that subjective softness is a complex summation that comes as a mental response from the evaluation of sensory inputs. This connotes an important distinction between subjective softness and directly sensed stimuli. If subjective softness is an interpreted property, it involves reference of sensed neural patterns to neural patterns already established in the brain and, as such, falls within the domain of aesthetics. As an interpretive property, the perceived softness of a paper tissue is then extremely complex and correlations for a single physical property beyond those experienced in this work can hardly be expected. Correlations can be developed only by limiting the subject's perception to a given physical parameter, which as this work has shown is difficult. Most likely, such correlations, if they could be developed, would have very narrow limits of applicability.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the contributions of Mr. Willmer A. Wink for his discussions, Mr. John D. Hankey for the fiber analysis work, Messrs. Carlt W. Denzer and Russell F. Tyler for the densitometer and Chapman smoothness tests, Messrs. Hugh M. Corbett and James Tierney for serving as subjects in the subjectiv tests, and Mrs. Elizabeth Cary for aid in the final preparation of this report.

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THE INSTITUTE OF PAPER CHEMISTRY

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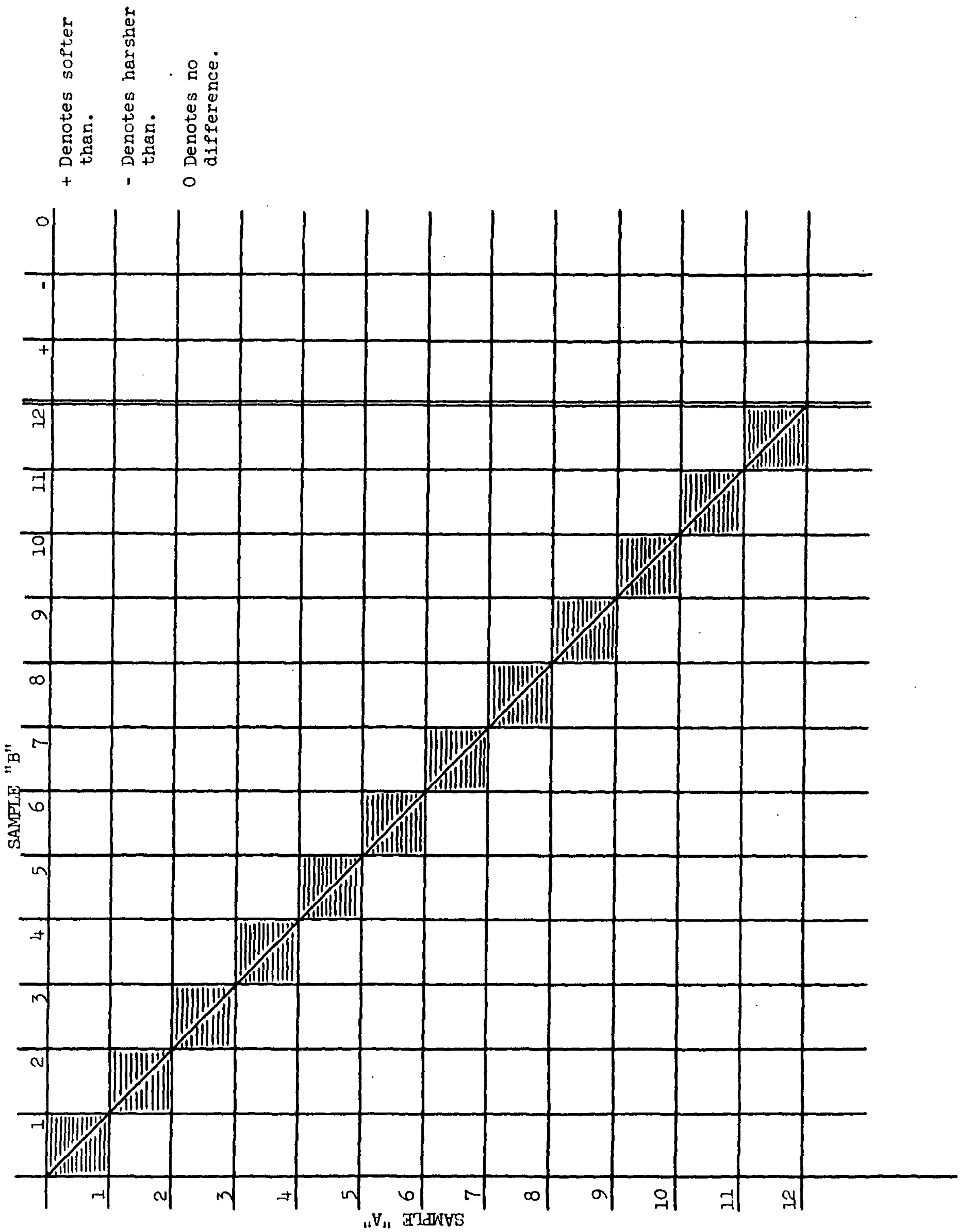
APPENDIX I

DATA SHEETS USED IN PAIRED-COMPARISON SUBJECTIVE SOFTNESS DETERMINATIONS



SAMPLE II

Sample I

	A 1	A 4	B 1	C 1	C 2	D 1	D 2	E 1	E 4	F 2	G 1	H 1	H 3	I 2	J 1	J 4	K 1	K 4	L 1	L 4
A-1																				
A-4																				
B-1																				
C-1																				
C-2																				
D-1																				
D-2																				
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K-4																				
L-1																				
L-2																				

Sample I vs. Sample II:

+ Denotes softer.

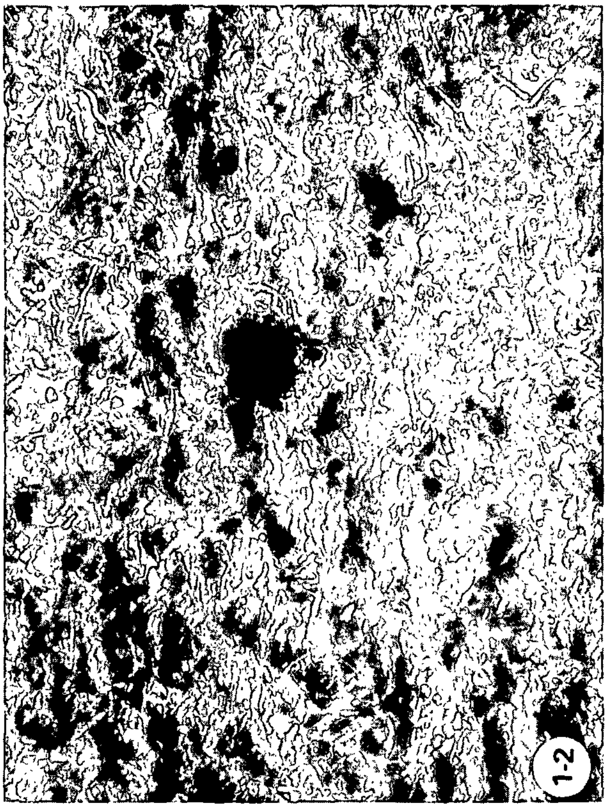
- Denotes harsher.

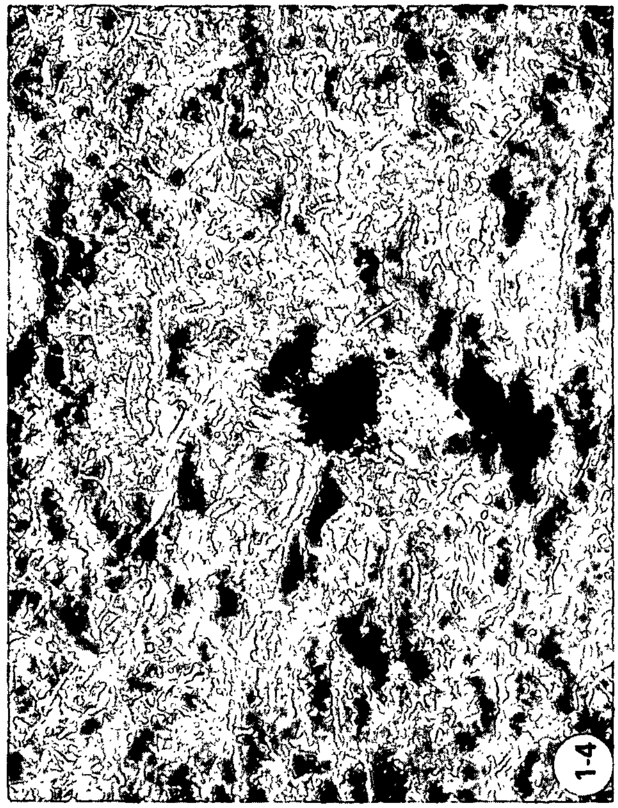
0 Denotes no differences.

APPENDIX II

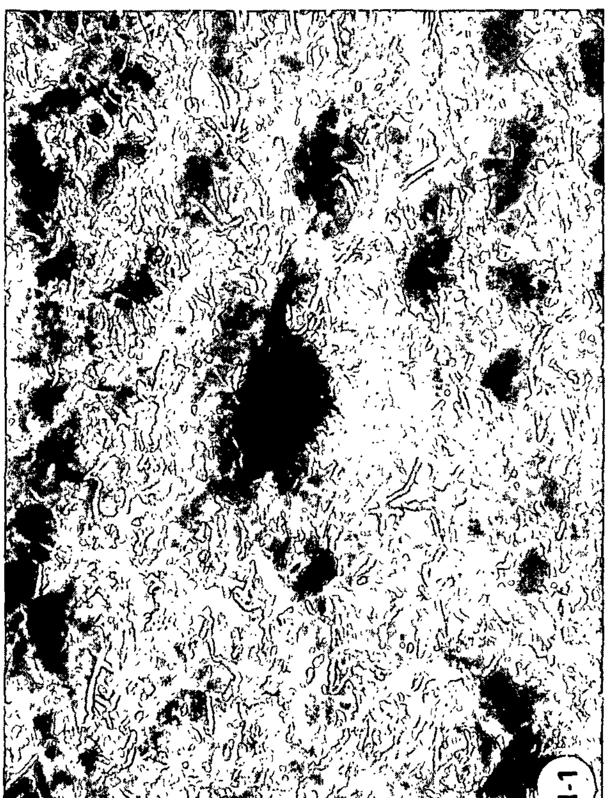
20x GRAZING ANGLE (85°) PHOTOGRAPHS OF TOILET TISSUE SPECIMENS

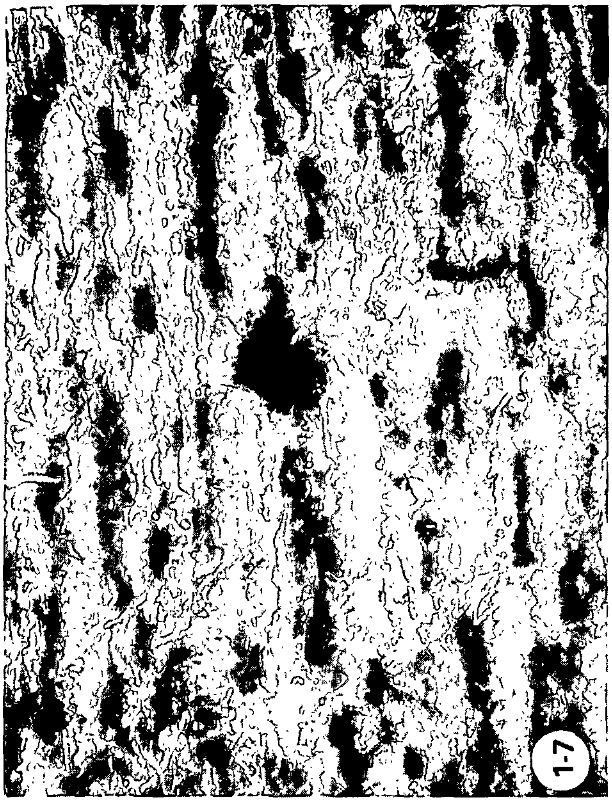
LIGHT INCIDENT IN THE MACHINE DIRECTION

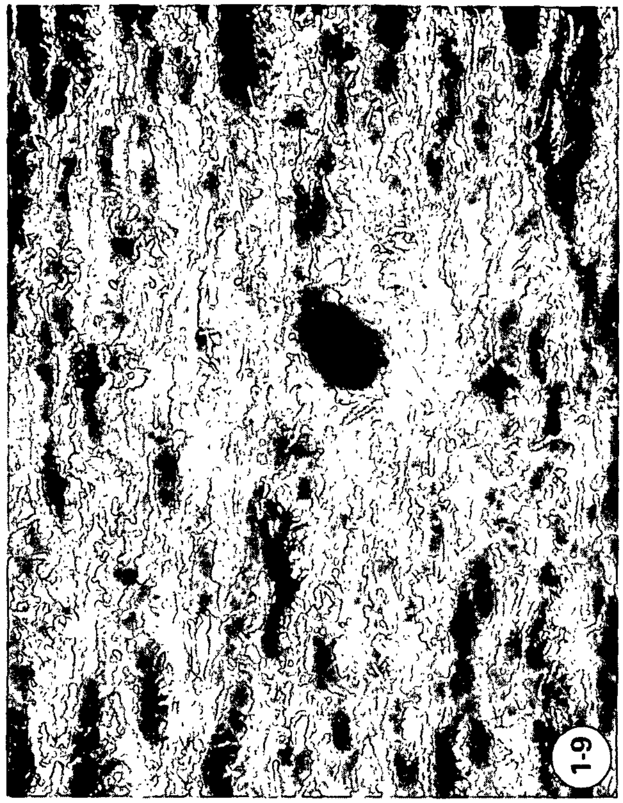




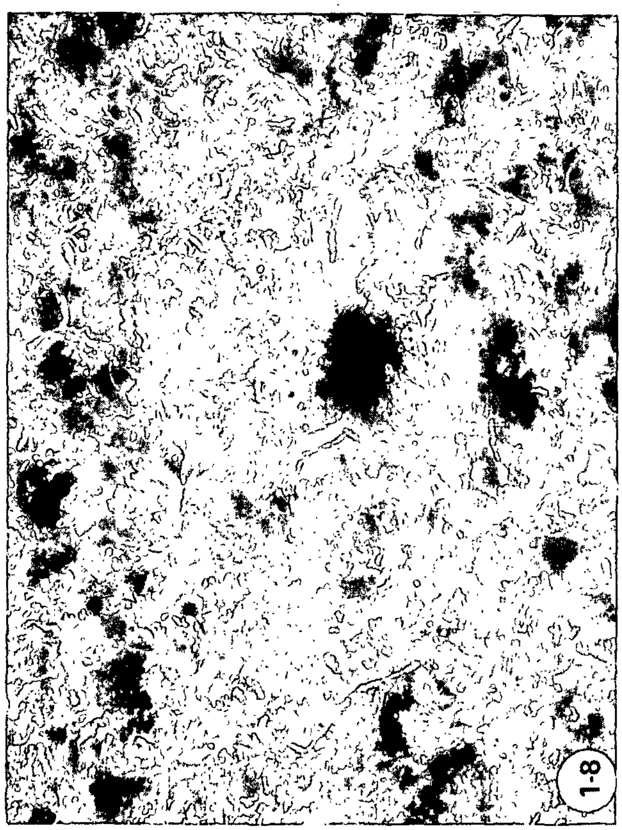
M.D. →

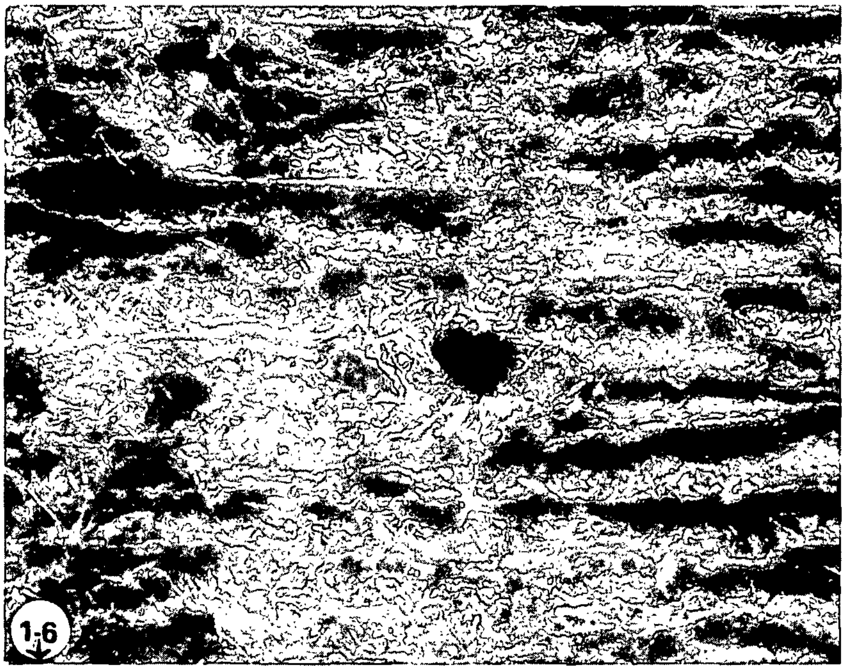


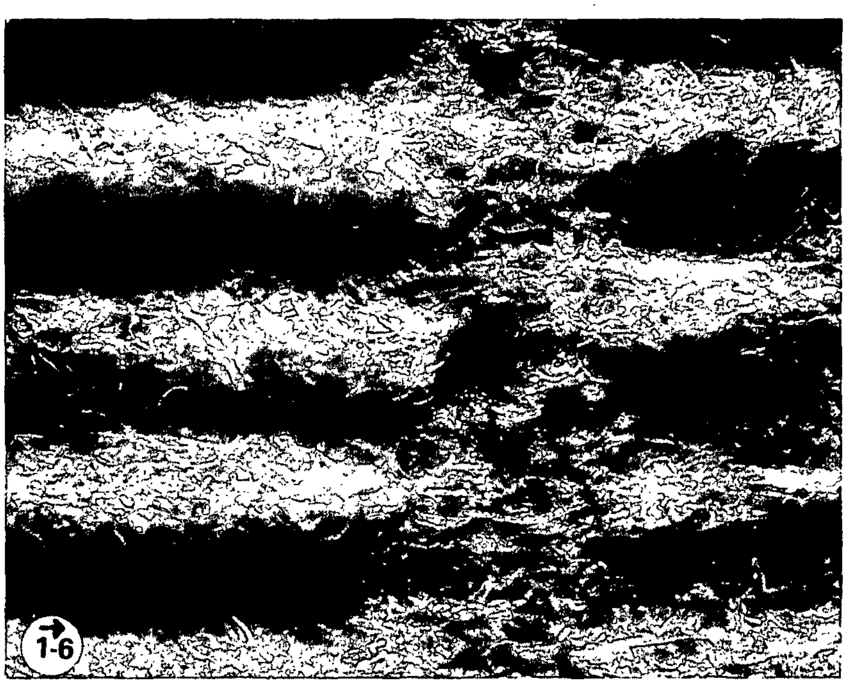




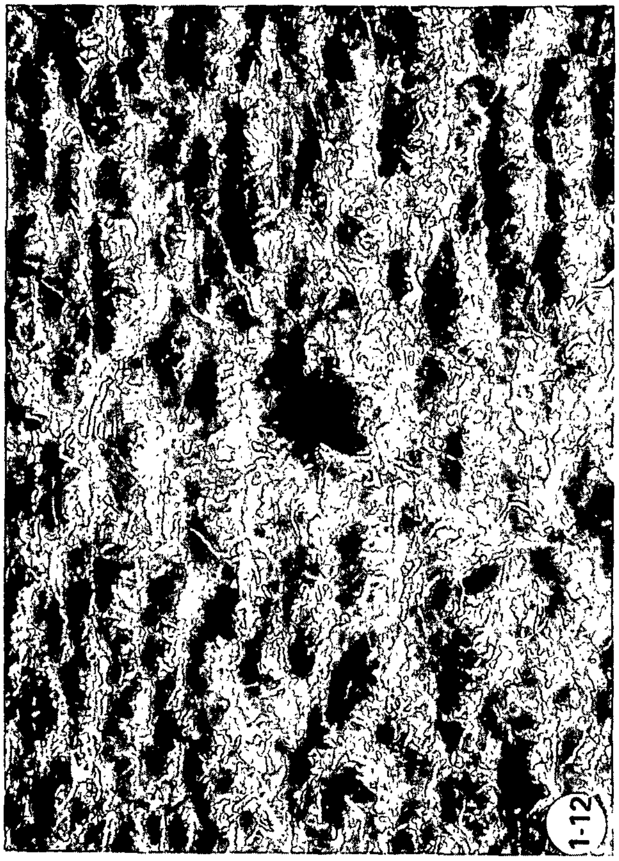
M.D.




1·6


1·6

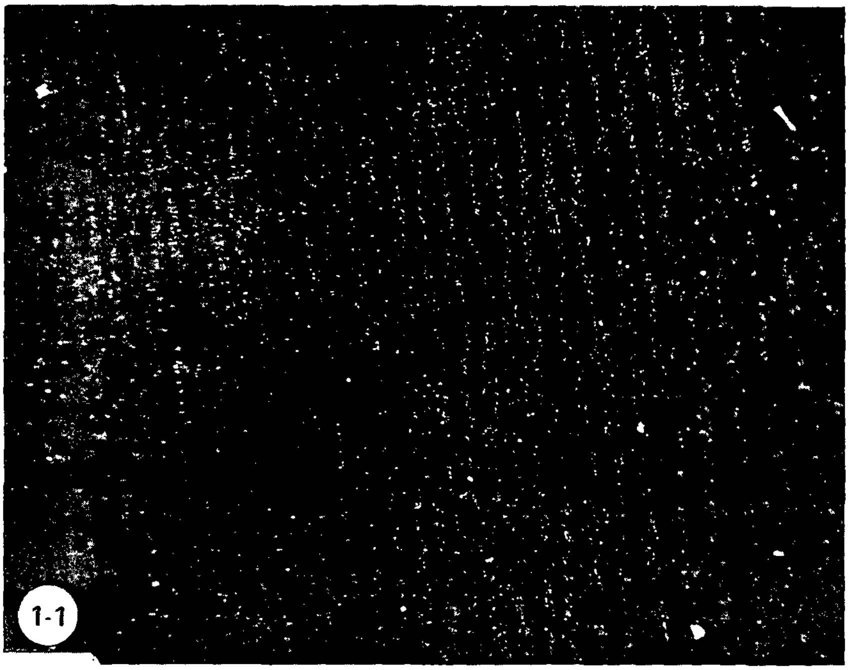
M.D. →

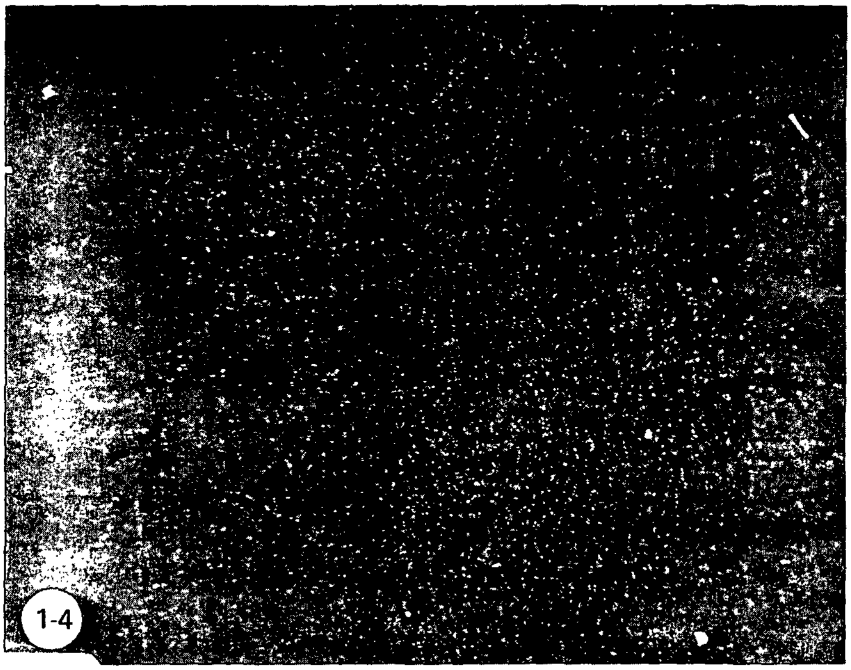


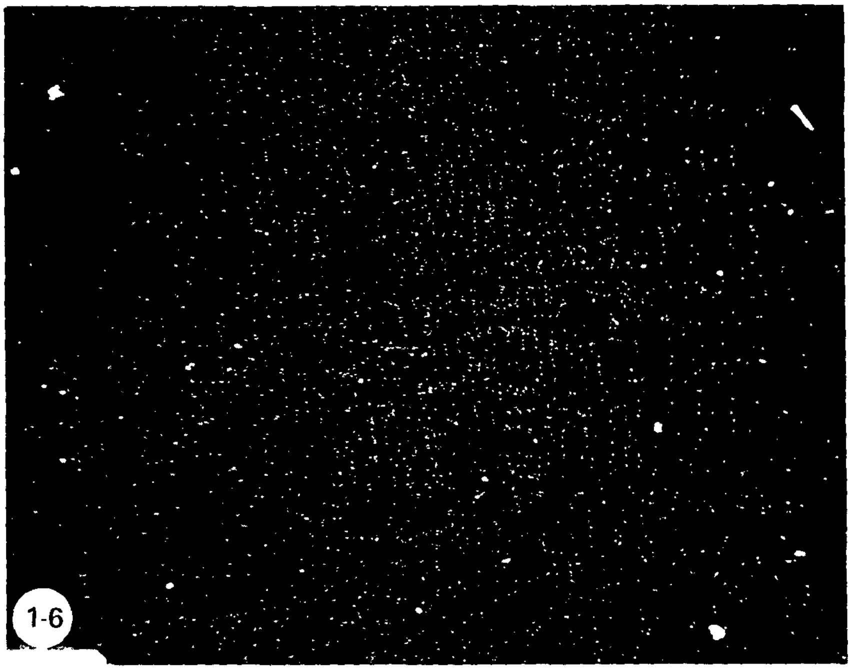
APPENDIX III

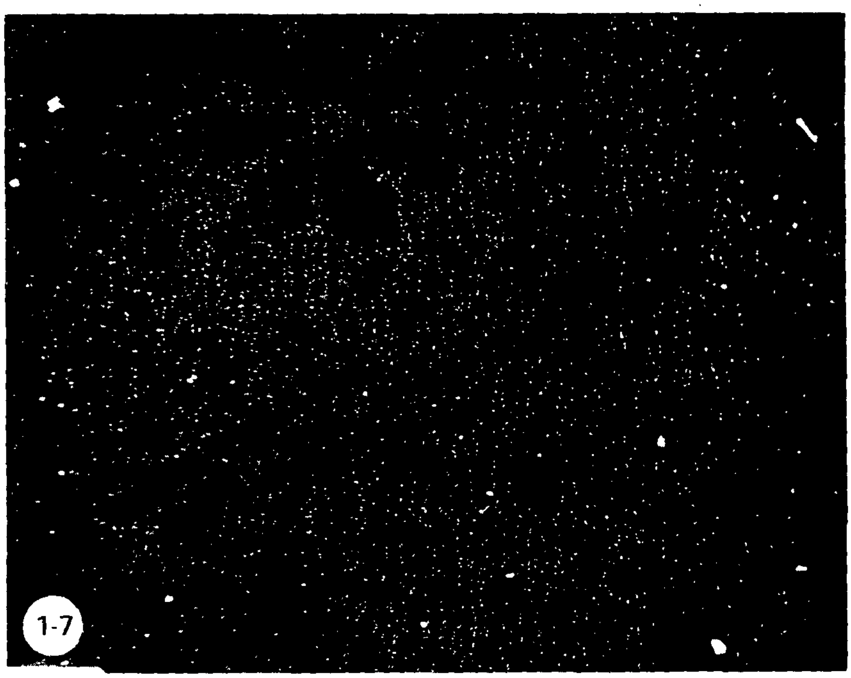
CHAPMAN SMOOTHNESS PHOTOGRAPHS OF TOILET TISSUE SAMPLES AT 5.04-g./m.^{2} LOAD

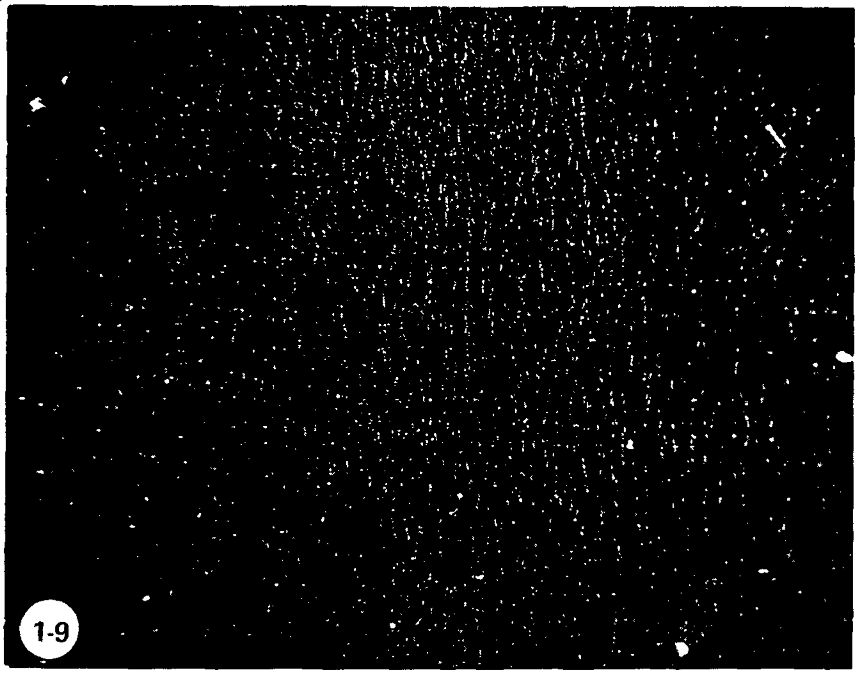
(M.D. ←)


1-1


1-4






1-9

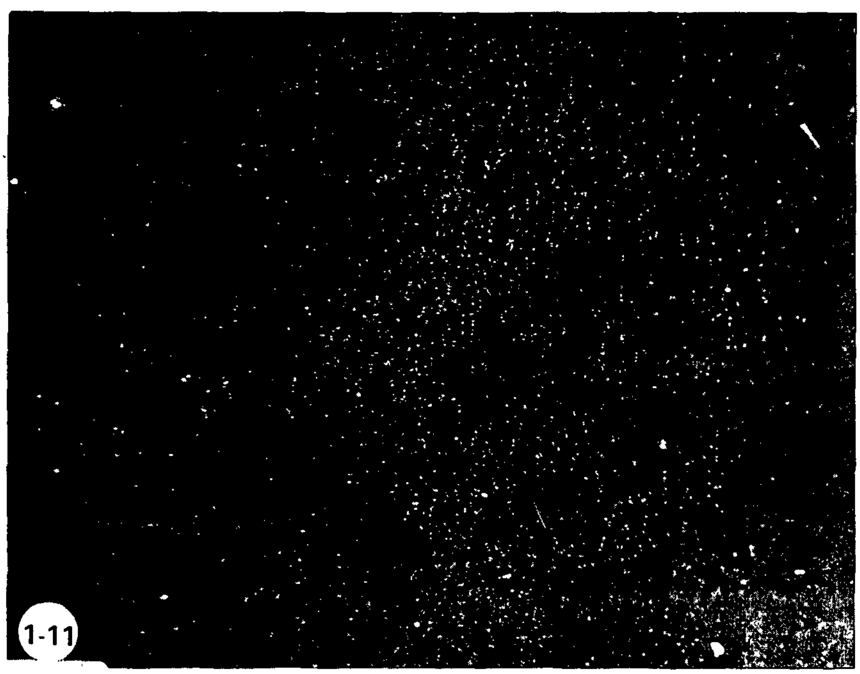

1-11

TABLE XII

FIBER FURNISH ANALYSES OF SELECTED SAMPLES

Code No. 2782-	Fiber Content	%[a]	Species Identification	Comments
C-1	Softwood alpha grade of bleached sulfite Softwood bleached kraft Hardwood bleached kraft	45- 50 10-	Softwood sulfite: Spruce and/or hemlock and true fir; trace of white pine. Softwood kraft: Douglas-fir, hard pine (ponderosa and/or lodgepole), spruce and/or hemlock, cedar, and true fir. Hardwood kraft: Species of gum.	Softwood furnishes showed very large amounts of cutting and fibrillation; hardwood showed little cutting or fibrillation. Fibers showed large amounts of bending and crimping, also wrinkling and shriveling of the cell wall.
D-1	Softwood unbleached sulfite Softwood bleached sulfite Softwood bleached kraft Hardwood bleached kraft Groundwood	trace 30 20- 40- 15-	Softwood sulfite: Spruce and/or hemlock and true fir. Softwood kraft: Hard pine (probably southern yellow pine). Hardwood kraft: Gum, oak, yellow poplar, beech, and maple.	Softwood furnishes showed large amounts of cutting and fibrillation; hardwood showed little cutting or fibrillation. Groundwood furnish fairly coarse. Softwood less refined than C-1 softwood, higher percentage of fine hardwood than C-1.
E-1	Softwood bleached sulfite Softwood bleached kraft Hardwood bleached kraft Groundwood	45 5+ 45- 5	Softwood sulfite: Spruce and/or hemlock and true fir. Softwood kraft: Hard pine (probably southern yellow pine). Hardwood kraft: Gum oak, yellow poplar, and maple.	Similar to C-1; softwood less fibrillated, larger percentage of hardwood.
H-1	Softwood bleached kraft Hardwood bleached kraft	35- 65+	Softwood kraft: Hard pine (probably southern yellow pine). Hardwood kraft: Gum, oak, yellow poplar, and beech.	Softwood showed moderate amounts of cutting and fibrillation; hardwood showed relatively little cutting or fibrillation.
K-1	Softwood bleached sulfite Softwood bleached kraft Hardwood bleached sulfite Groundwood	trace+ 75 10+ 10	Softwood sulfite: Spruce and/or hemlock. Softwood kraft: Douglas-fir, spruce and/or hemlock, hard pine (ponderosa or lodgepole), and white pine. Hardwood sulfite: Alder.	Softwood showed moderate amounts of cutting and fibrillation; hardwood showed relatively little cutting or fibrillation. Groundwood was fairly coarse.
1-5	Softwood bleached kraft Hardwood bleached sulfite Groundwood	20 50- 30+	Softwood kraft: Spruce and/or hemlock and hard pine (probably jack pine), trace Douglas-fir. Hardwood sulfite: Aspen. Groundwood: Principally hardwood.	Softwood showed moderate amounts of cutting and fibrillation; hardwood showed relatively little cutting or fibrillation. Furnish contained a large amount of fines, principally flour from the groundwood pulp. Groundwood medium to finely ground.

[a] Reported to nearest 5%.

TABLE XII (CONTD.)

FIBER FURNISH ANALYSES OF SELECTED SAMPLES

Code No. 2782-	Fiber Content	%[a]	Species Identification	Comments
1-6	Softwood bleached sulfite Softwood bleached kraft Hardwood bleached kraft	5+ 55 40-	Softwood sulfite: Spruce and/or hemlock. Softwood kraft: Spruce and/or hemlock and hard pine (probably jack pine), traces of true fir, cedar, red or white pine, and Douglas-fir. Hardwood kraft: Aspen, birch, oak, maple, yellow poplar, ash, and cherry.	Softwood showed large amounts of cutting and fibrillation. hardwood showed relatively little cutting and moderate fibrillation.
1-7	Softwood bleached sulfite Softwood bleached kraft Hardwood bleached sulfite Groundwood	10+ 35+ 35 15+	Softwood sulfite: Spruce and/or hemlock and true fir. Softwood kraft: Spruce and/or hemlock, hard pine (probably jack pine), and Douglas-fir. Hardwood sulfite: Aspen and birch.	Softwood and hardwood furnishes showed fairly large amounts of cutting and moderate fibrillation. Large amounts of fiber debris (pieces of fibers and vessel elements, parenchyma cells, groundwood flour); not too much fine fibrillar material. Groundwood extremely finely ground.
1-9	Softwood bleached kraft Hardwood bleached sulfite Groundwood	35 60 5-	Softwood kraft: Spruce and/or hemlock, true fir, and hard pine (probably jack pine). Hardwood sulfite: Aspen.	Softwood and hardwood furnishes showed moderate amounts of cutting and fibrillation. Groundwood was finely ground.
1-10	Softwood bleached sulfite Softwood bleached kraft Hardwood bleached kraft	25 60- 15+	Softwood sulfite: Spruce and/or hemlock and true fir. Softwood kraft: Spruce and/or hemlock, true fir, and hard pine (jack or southern yellow pine). Hardwood kraft: Gum, oak, and yellow poplar.	Softwood showed fairly large amounts of cutting and fibrillation. Hardwood showed very little cutting and a moderate amount of fibrillation.

[a] Reported to nearest 5%.